Flip mode emittance analysis

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MICE CM58

Overview

- Emittance change analysis updates
  - Reconstruction / detector performance correction
  - Systematic uncertainties
  - Full transmission requirement bias / correction
  - Updated results
  - Outstanding issues
- Canonical angular momentum analysis (time permitting)

Recap

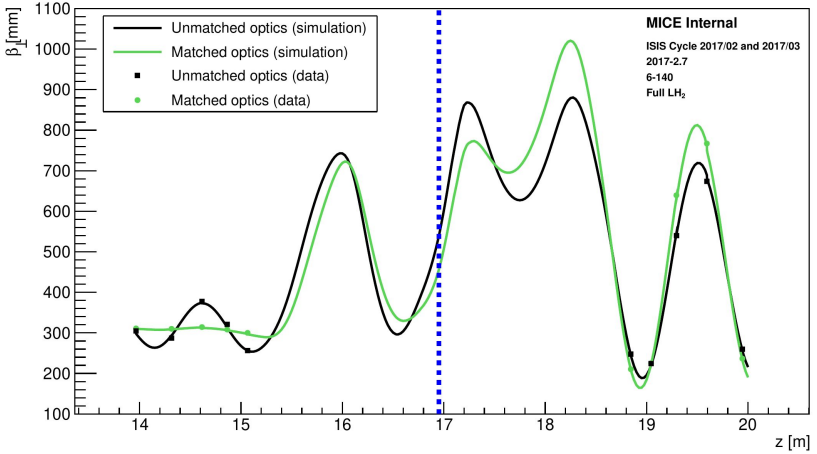
- Analysis aim: measure emittance change across the LiH and LH2 absorbers

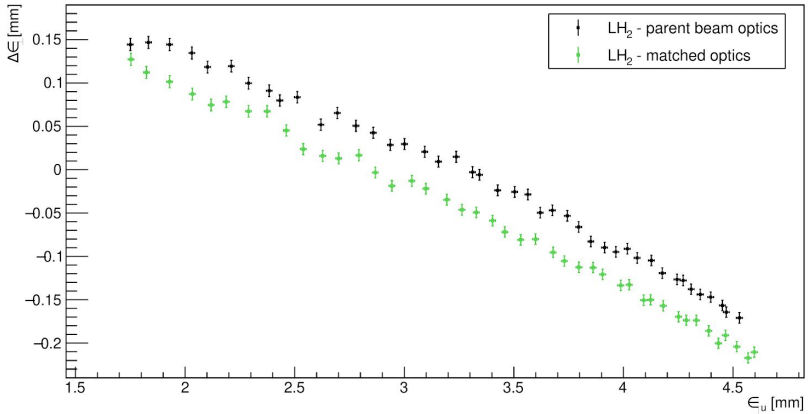
$$\Delta\varepsilon_{\perp} = \varepsilon_{\perp}^{d} - \varepsilon_{\perp}^{u}$$

- Beam sampling applied to the reconstructed upstream sample
  - to match the beam to the cooling channel
  - to reduce beta at the absorber, improving the cooling performance
  - provides flexibility to sample beams with specific emittances
- Currently analysing the 4,6,10 - 140 MeV/c data

Beam Sampling

- In this analysis, beams with α = 0.0, β = 310 mm are sampled at the upstream reference plane
- Six beams with different emittances are sampled:
  - 1.5, 2.5 mm from the 4 mm dataset
  - 3.5, 4.5 mm from the 6 mm dataset
  - 5.5, 6.5 mm from the 10 mm dataset





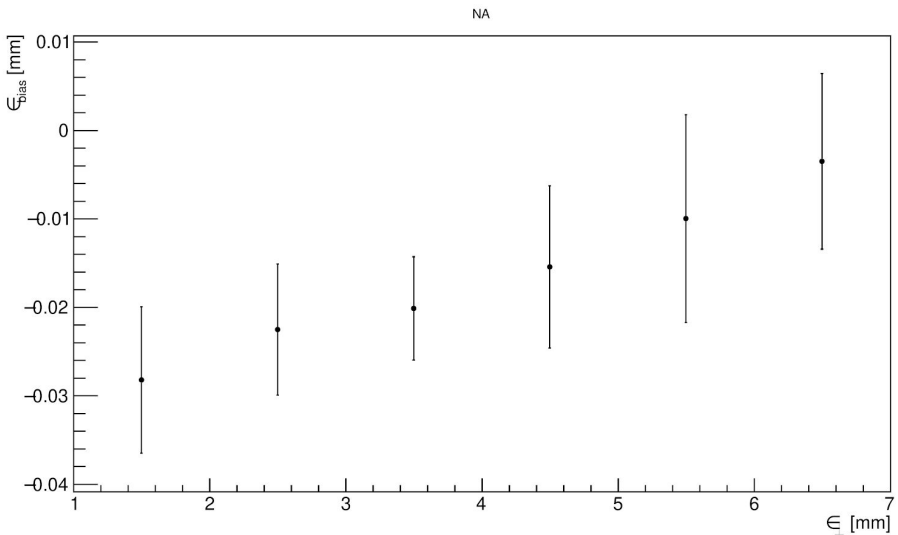
Detector performance bias/correction

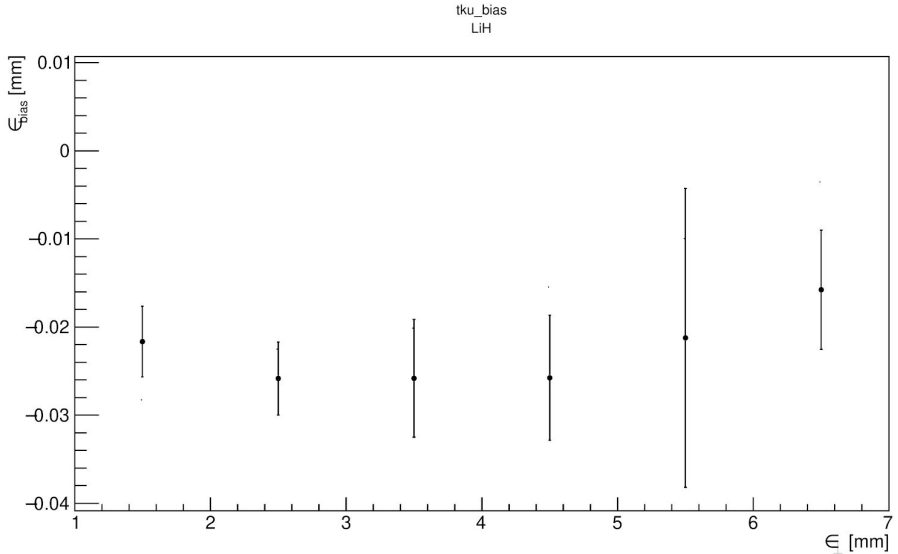
- The detector resolution and bias in the reconstruction algorithm lead to a biased emittance measurement
- Calculate bias at the TKU and TKD reference planes (using multiple 5000 event independent samples) as:

$$\varepsilon_{bias} = \langle \varepsilon_{reco} - \varepsilon_{truth} \rangle$$

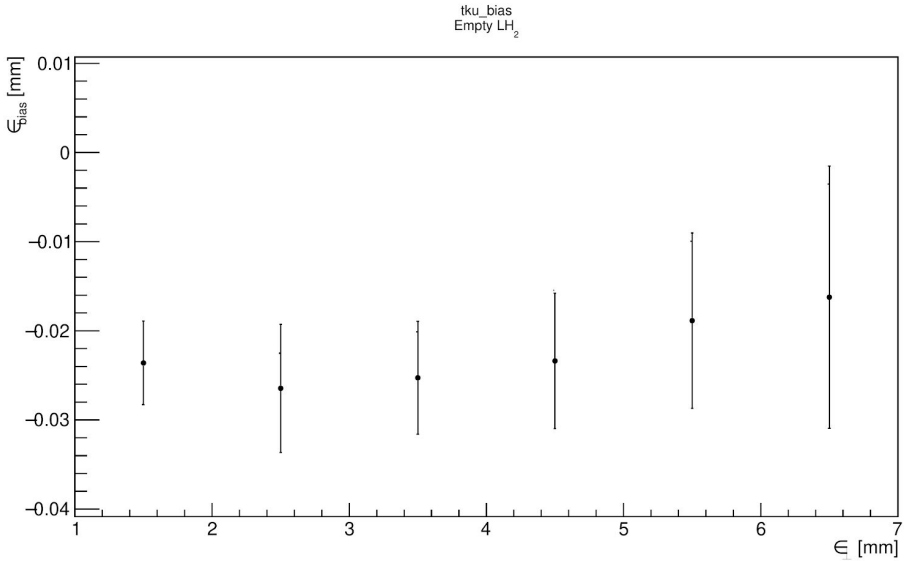
- Applied for all the sampled beams [1.5, 2.5, … , 6.5] mm
- Hybrid MC used (produced by extracting a data sample at TKU5, applying KDE smearing then sampling from the resulting pdf)

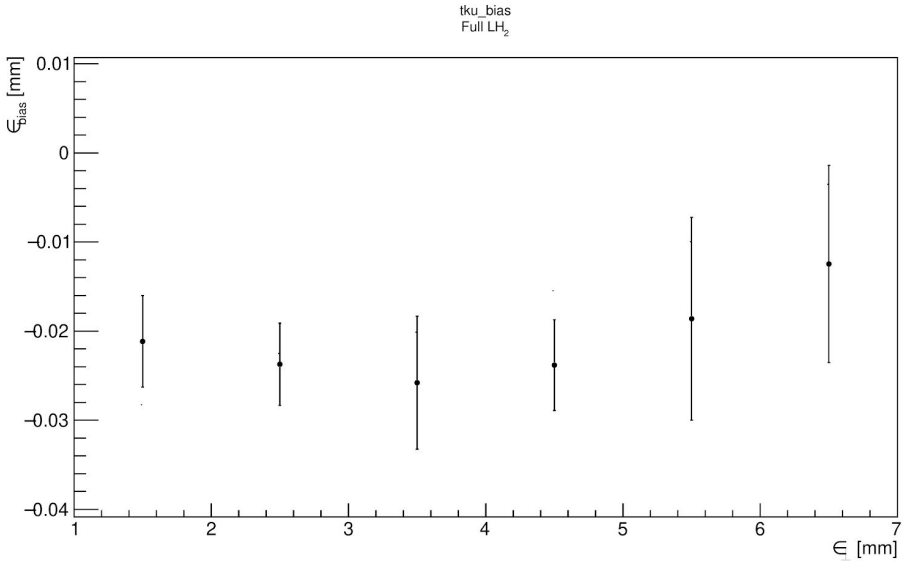
TKU bias: No absorber & LiH



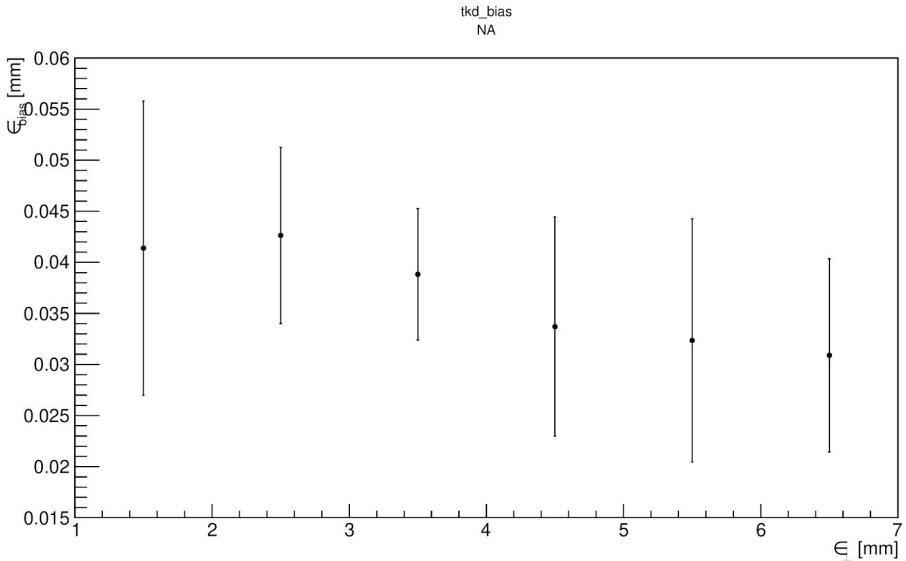


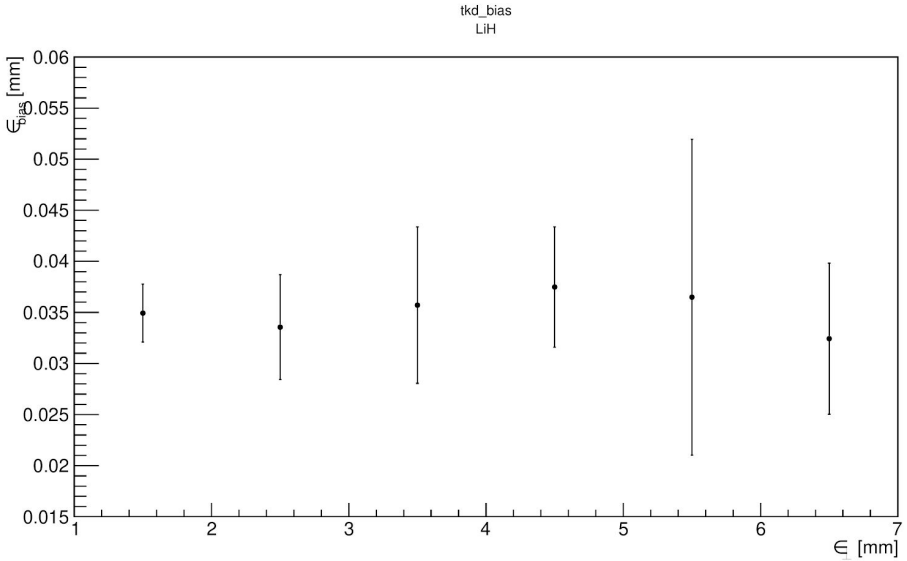
TKU bias: Empty LH2 & Full LH2



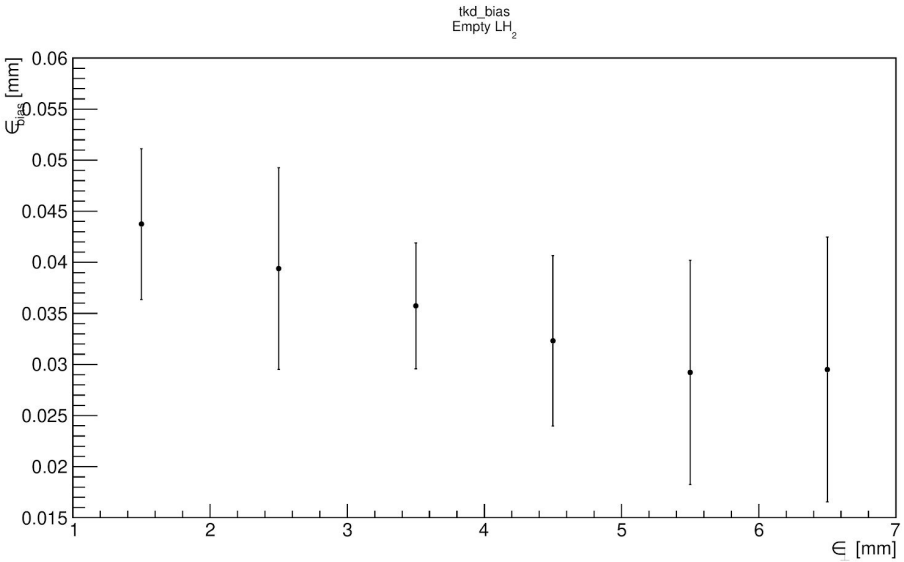


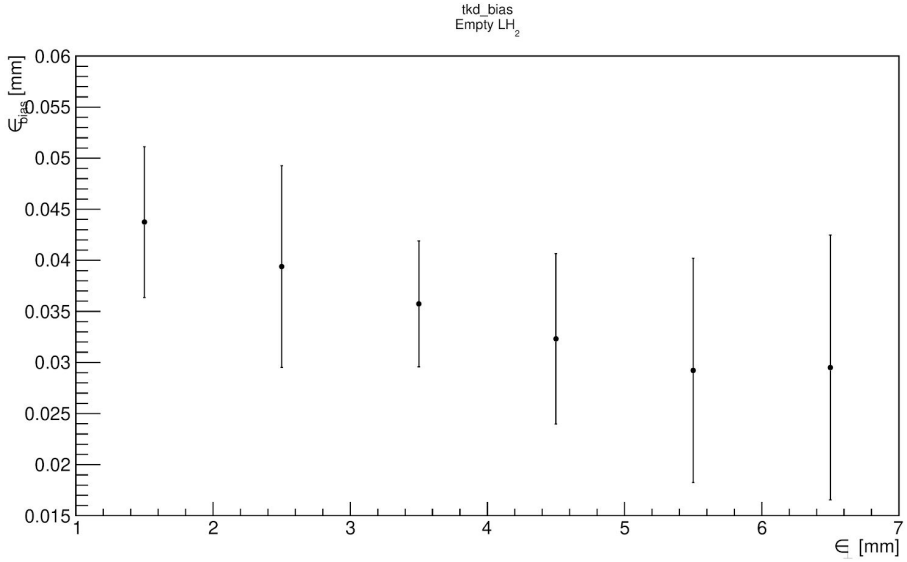
TKD bias: No absorber & LiH





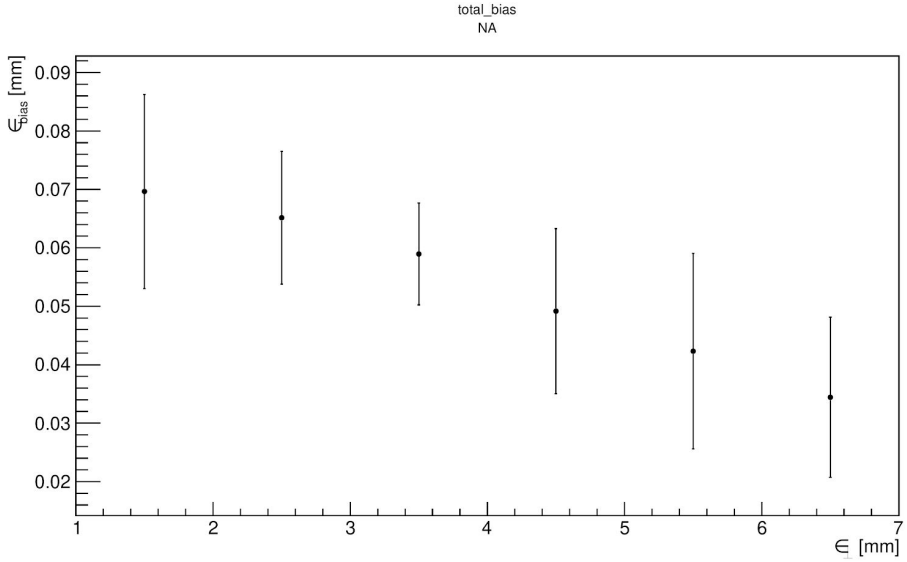
TKD bias: Empty LH2 & Full LH2

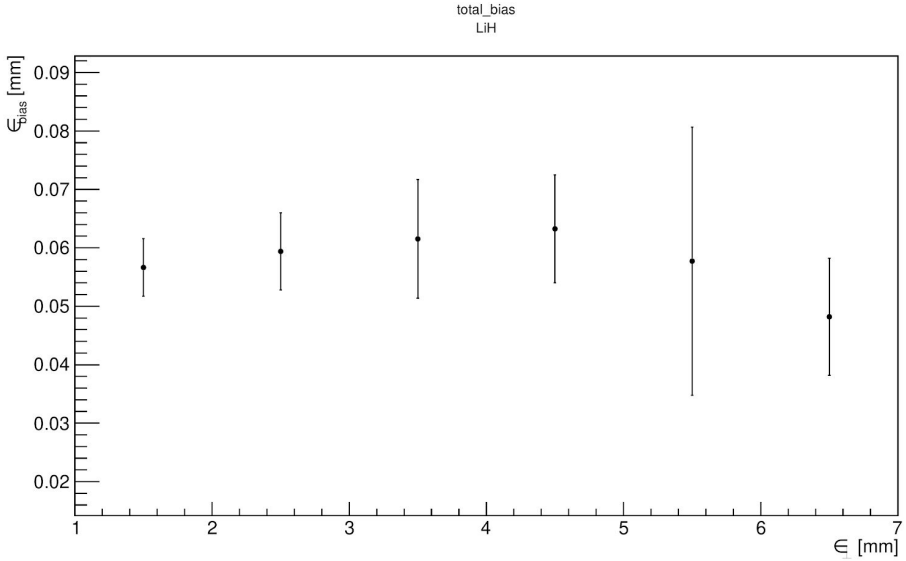




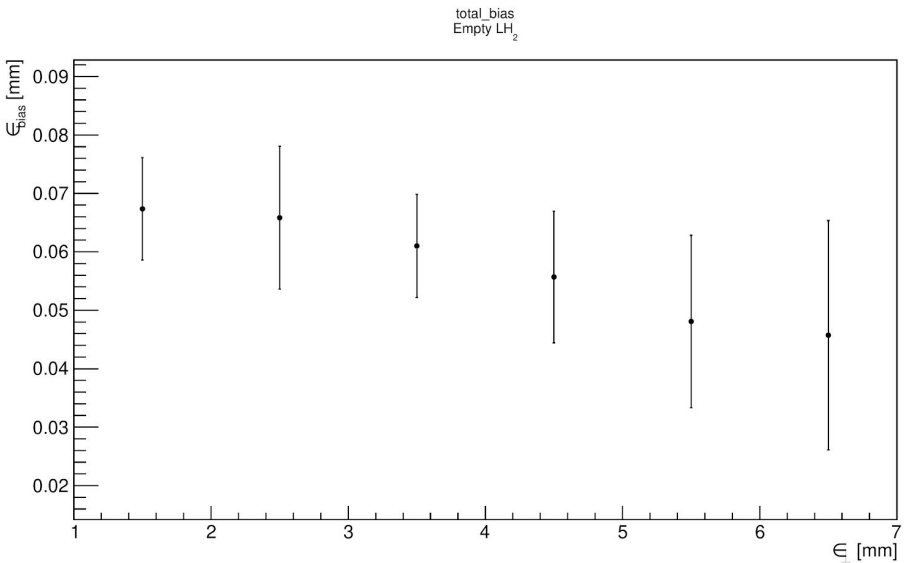
Bias on emittance change: No absorber & LiH

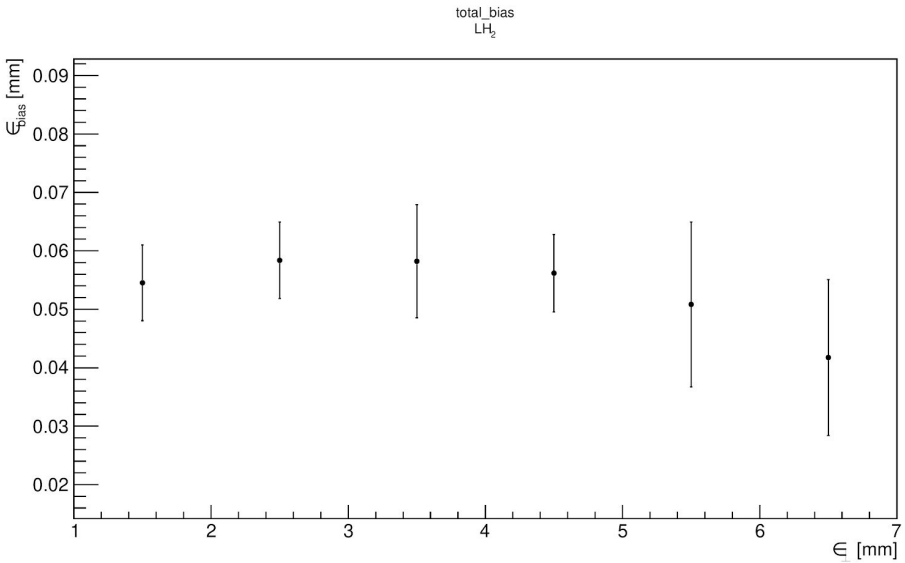
$$\Delta\varepsilon_{bias} = \varepsilon^{d}_{bias} - \varepsilon^{u}_{bias} = \Delta\varepsilon_{reco} - \Delta\varepsilon_{truth}$$





Bias on emittance change: Empty LH2 & Full LH2





Corrections are similar between the four different cooling channel settings

Systematic uncertainty (1)

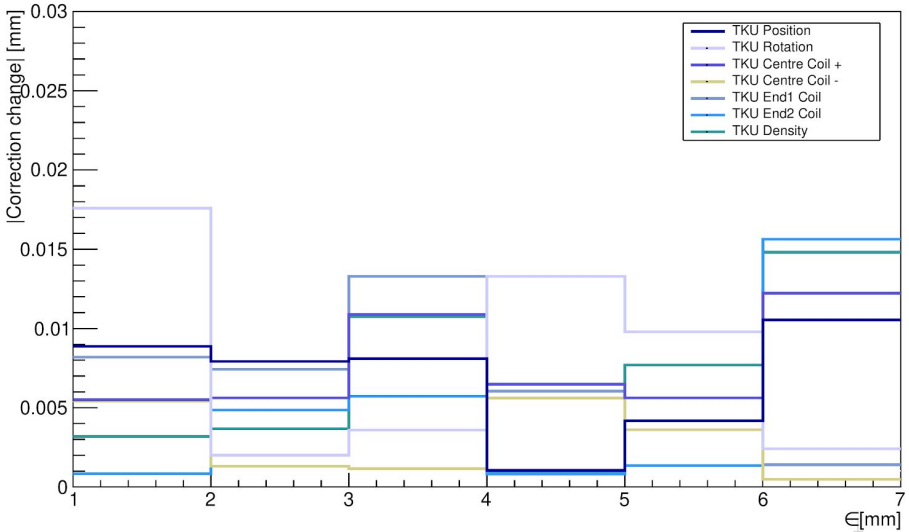
- Correction procedure assumes perfect knowledge of the hardware
- Aim: understand how the uncertainty in the detectors translates into the uncertainty on the emittance change
- Procedure: introduce alterations into the simulation of the detectors; the resulting variation in the correction is considered as the uncertainty in the correction

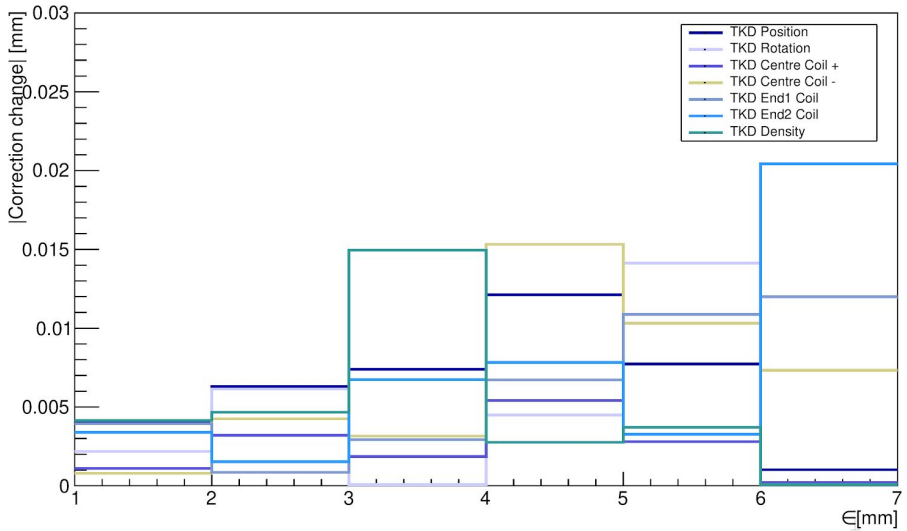
Systematic uncertainty (2)

- Alterations to the detector simulations are introduced one by one, for each tracker, as follows:
  - Tracker displaced horizontally by 3 mm
  - Tracker rotated in the horizontal plane by 3 mrad
  - Centre coil field strength varied by 3 %
  - End coils (1&2) field strength varied by 5 %
  - Tracker material density increased by 50 %
- Total systematic uncertainty - quadratic sum of all sources of uncertainty
- **Warning**: plots to follow contain samples with ONLY 8k - 15k events
- More hybrid MC to be produced (current bottleneck)

Systematic uncertainty - in progress...

- Uncertainties on the total correction for the No absorber case





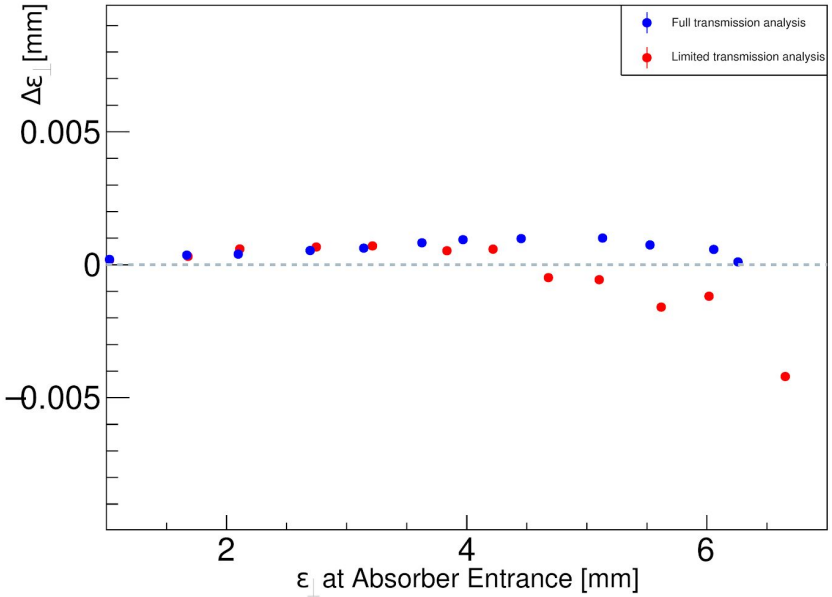
Full transmission bias study (1)

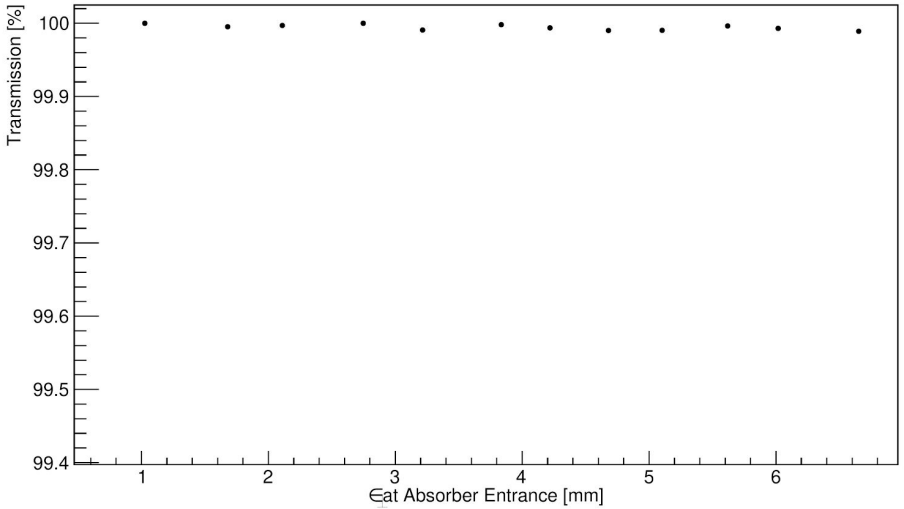
- Imposing a full transmission requirement in order to eliminate the bias due to particle loss introduces another bias
  - Removal from the analysis of particles that scrape the apertures / are lost due to scattering in the absorber artificially reduces the heating effect, resulting in an apparent enhanced cooling
- Aim: study the magnitude of the bias as function of input beam emittance; then apply as a correction

Full transmission bias study (2)

- Procedure:
  - Study the **MC Truth** of beams that were reconstructed with the full transmission requirement ON and OFF (for beams with input emittances in the range of interest)
  - Assess the emittance change between the **entry and exit planes of the absorber**, for the two scenarios
  - Assign the difference in the emittance change as the bias/correction to be applied

No absorber





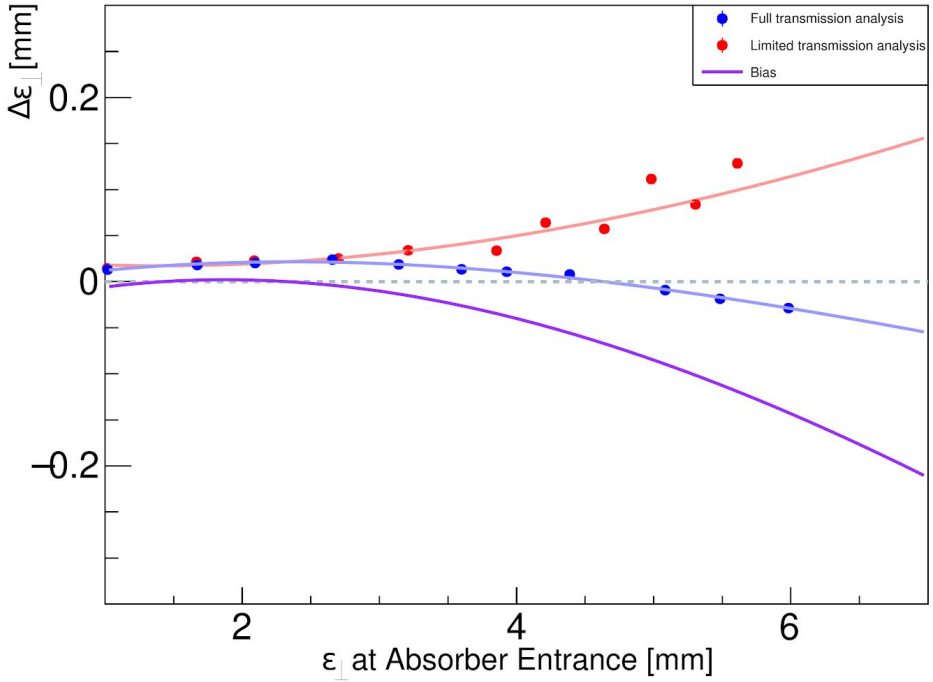
Essentially no bias present as the beams do not cross any material

Some scraping / minor losses affect the higher emittance beams

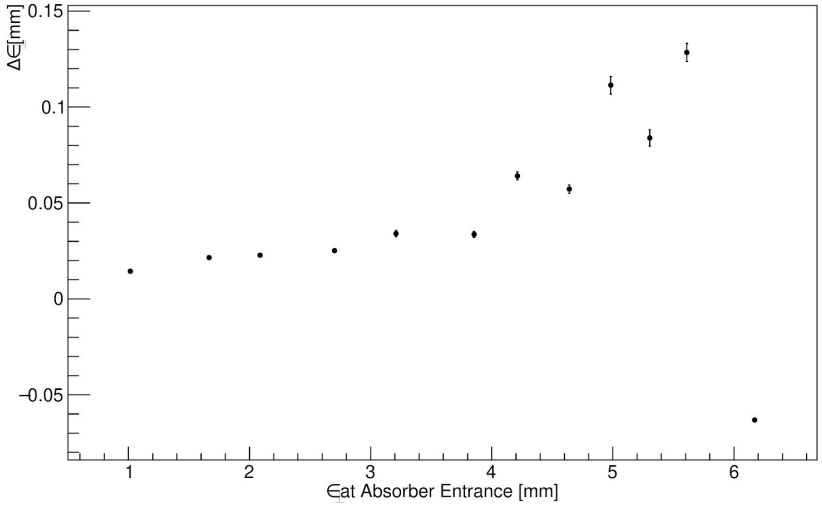
Empty LH2

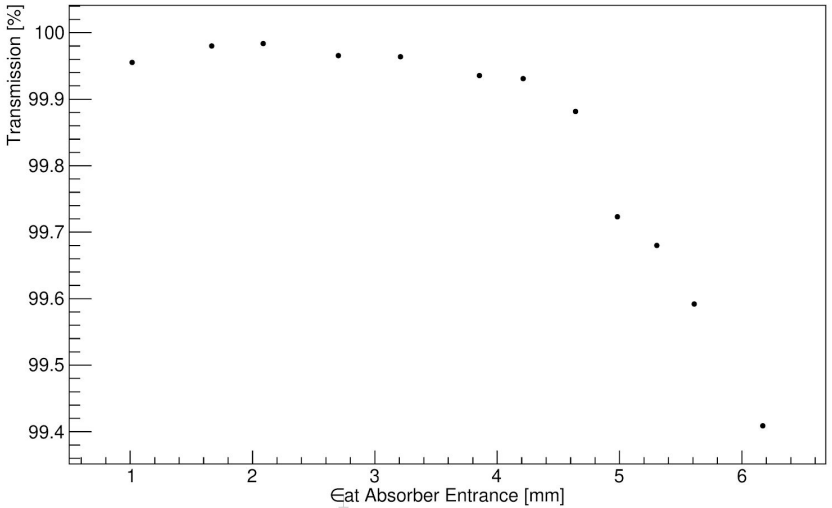
Bias, as a function of input emittance, shown in purple

Tricky to asses, as the emittance calculation starts to be affected by losses scraping at high emittance beams (next slide)



Empty LH2 - limited transmission beams



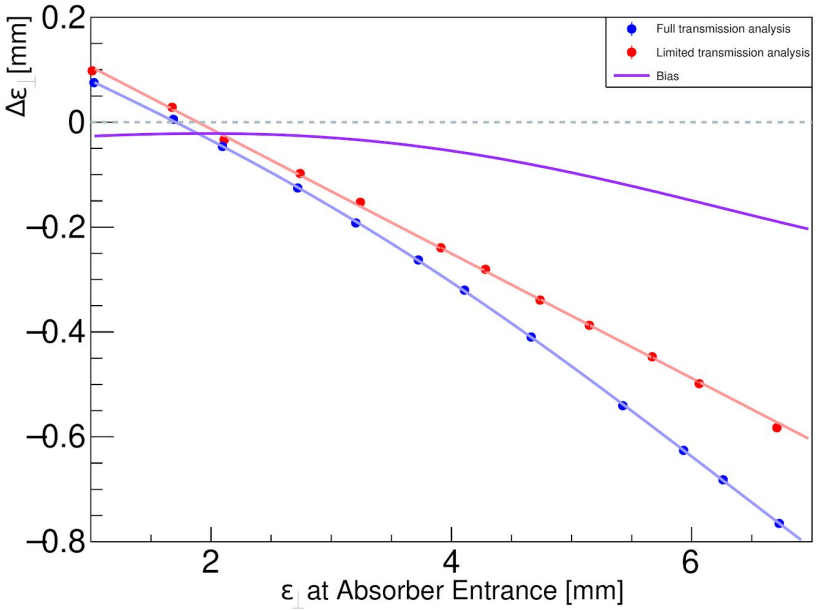


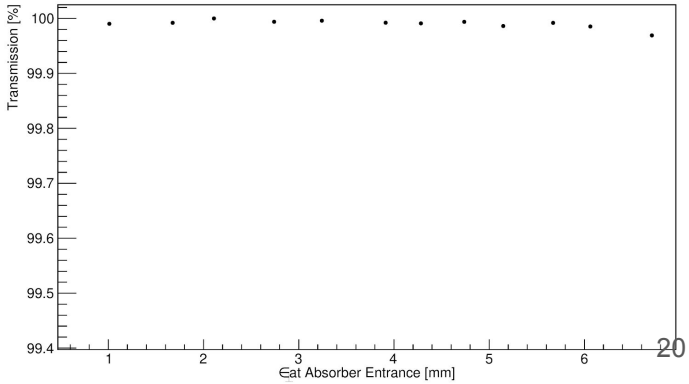
LiH

Limited transmission analysis - linear cooling behaviour as there are virtually no particle losses across the extent of the absorber

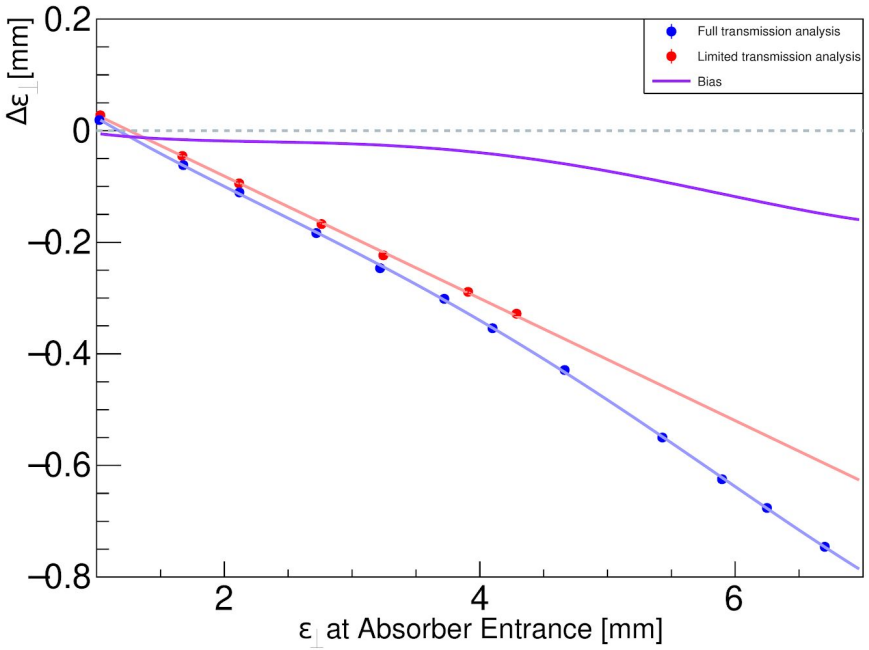
Full transmission analysis: enhanced cooling, effect stronger with growing input emittance

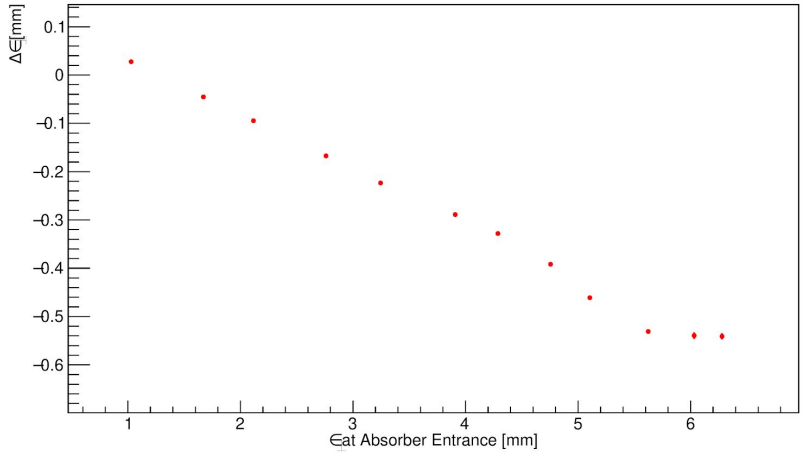
Bias: difference between the two fits, becomes significant at higher emittances

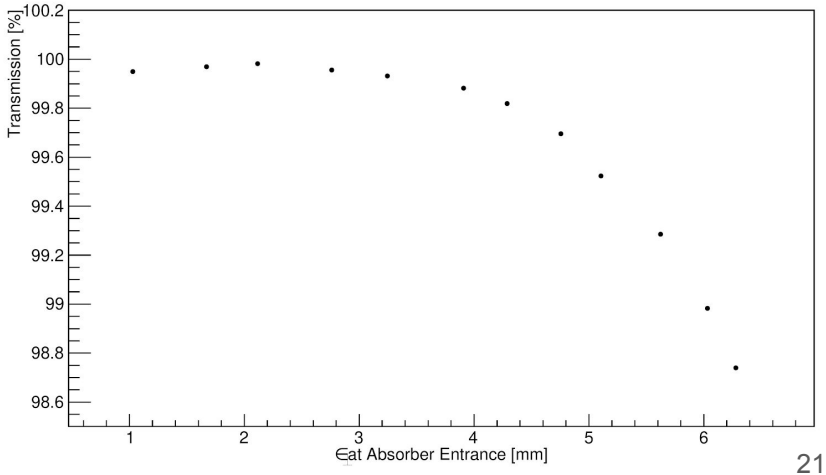




Full LH2







Difficult to asses at high emittances, removed points affected by losses. Linear cooling behaviour for the limited transmission assumed at high emittances as well

Full MC update

- Paolo and Dimitrije helped starting the official full MC production
- A first batch was completed
- Comparison with Data is good, no differences observed between locally produced and official MC
- Currently waiting for further production

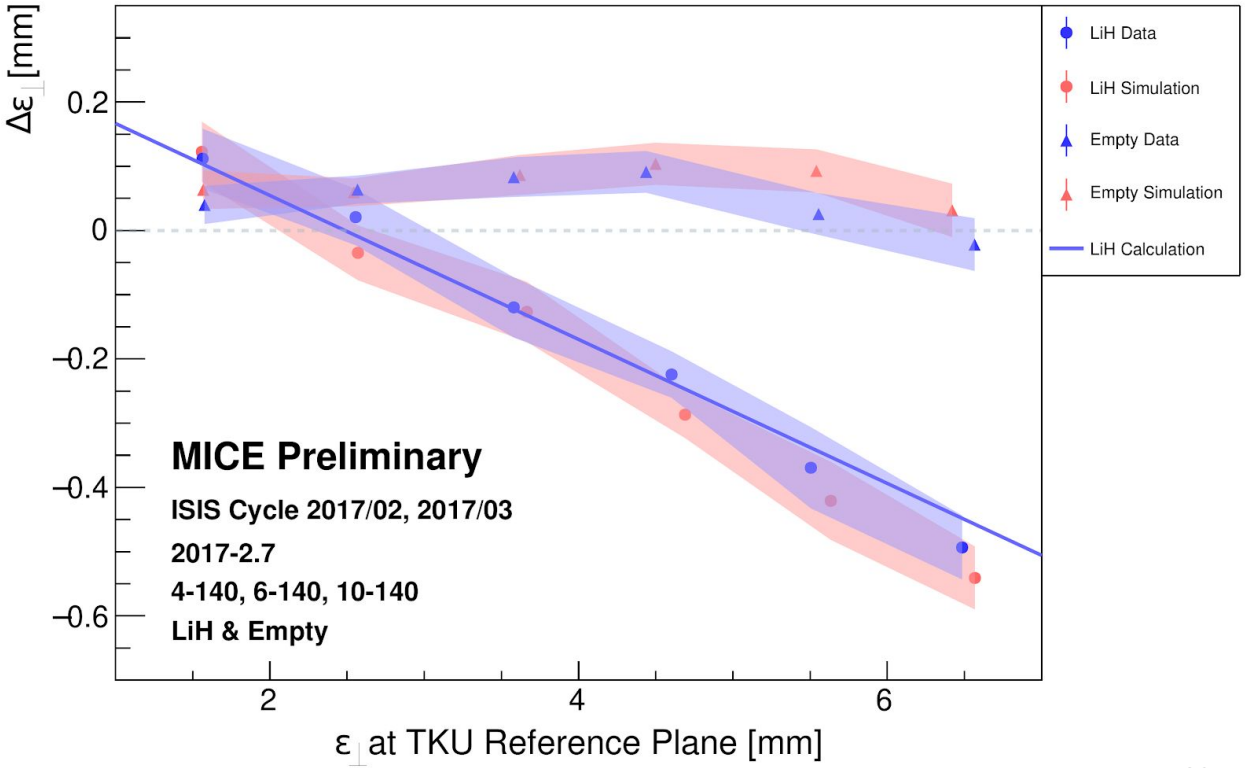
Emittance change: LiH

Corrections applied

Errors are systematics dominated. To be updated. Do not yet include an uncertainty on the transmission bias correction.

Cooling prediction calculated using the 3.5 mm beam parameters at the absorber

Good agreement Data / Simulation. Good agreement Data / calculation



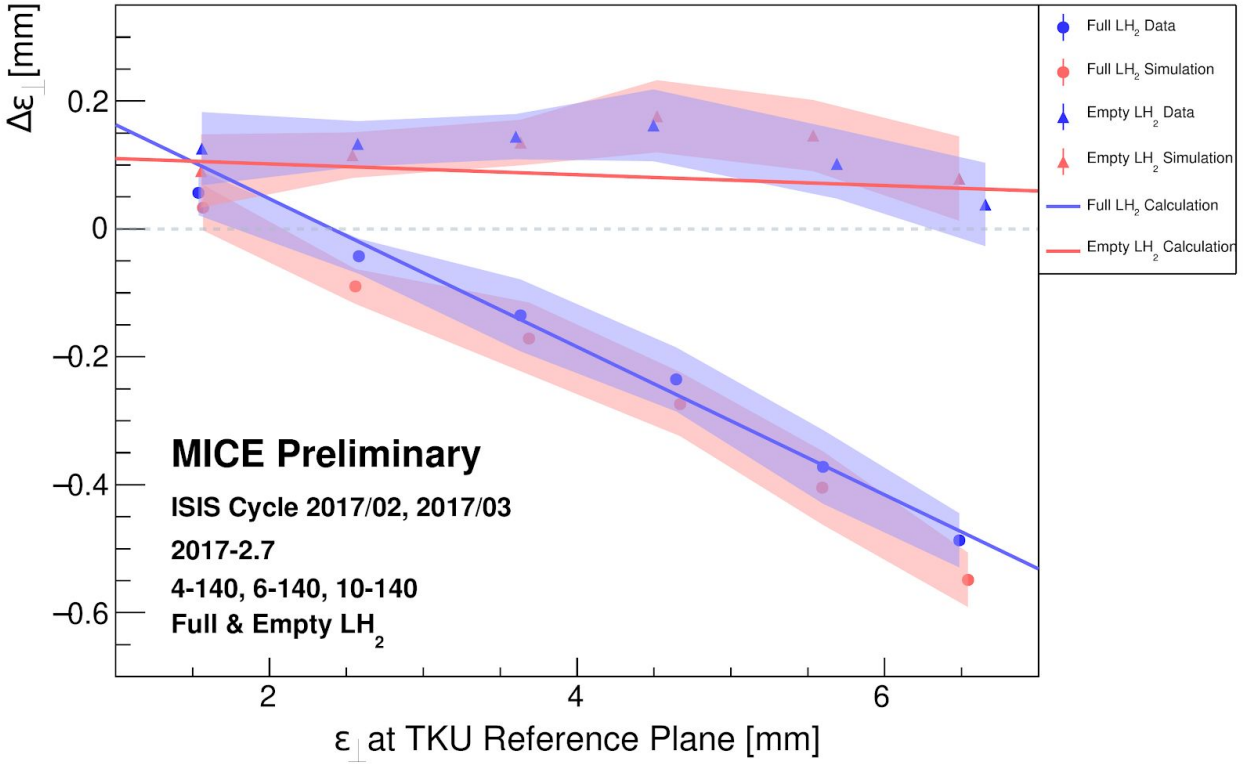
Emittance change: LH2

Corrections applied

Errors are systematics dominated. To be updated. Do not yet include an uncertainty on the transmission bias correction.

Cooling / heating prediction calculated using the 3.5 mm beam parameters at the absorber

Good agreement Data / Simulation. Good agreement Data / calculation



Emittance analysis - outstanding issues

- Finalise systematics uncertainties studies (requested more hybrid MC production from Dimitrije, also running locally)
- Improve understanding of the empty vessel transmission correction
- Calculate uncertainty on the transmission correction and add to the total uncertainty
- Expand to higher momentum beams
- Tidy up (summary tables, plots etc.)

Canonical Angular Momentum

$$L_{canon} = L_{kin} + L_{field}$$
$$L_{kin} = xp_y - yp_x$$
$$L_{field} = qrA \approx \frac{qr^2 B_z}{2}$$

For each particle, B_z at particle position is loaded from MAUS field map

1D Distributions

L_{kin} TKU

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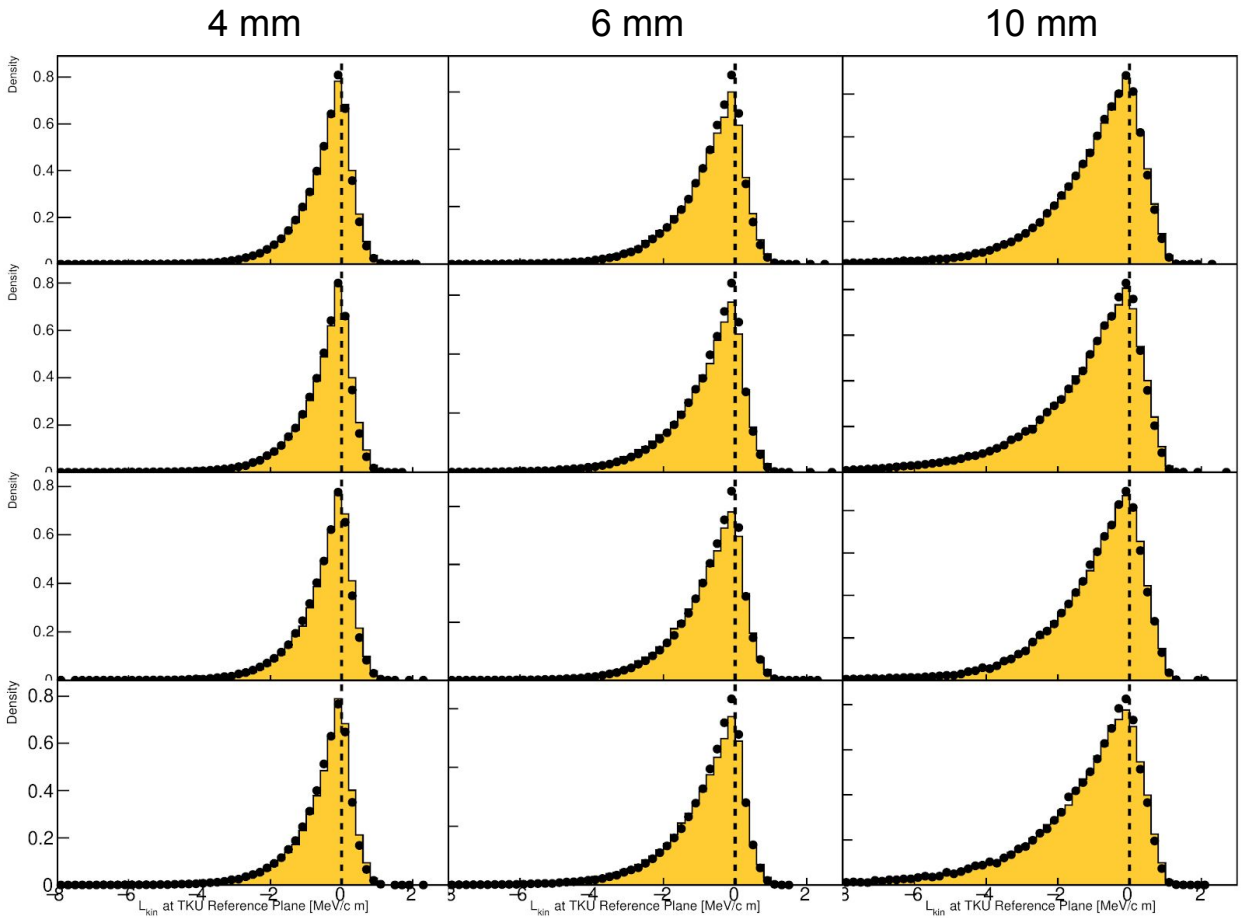
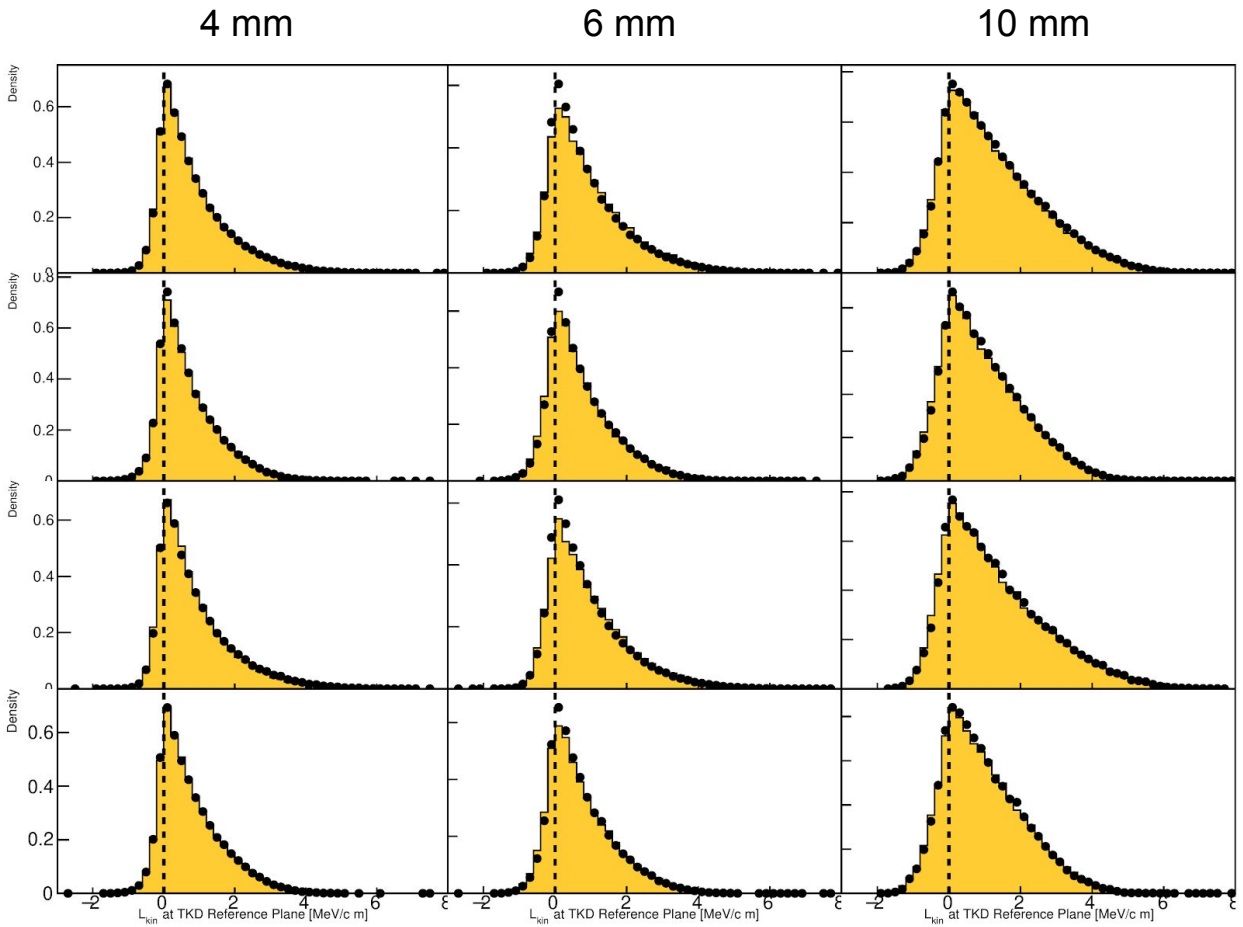


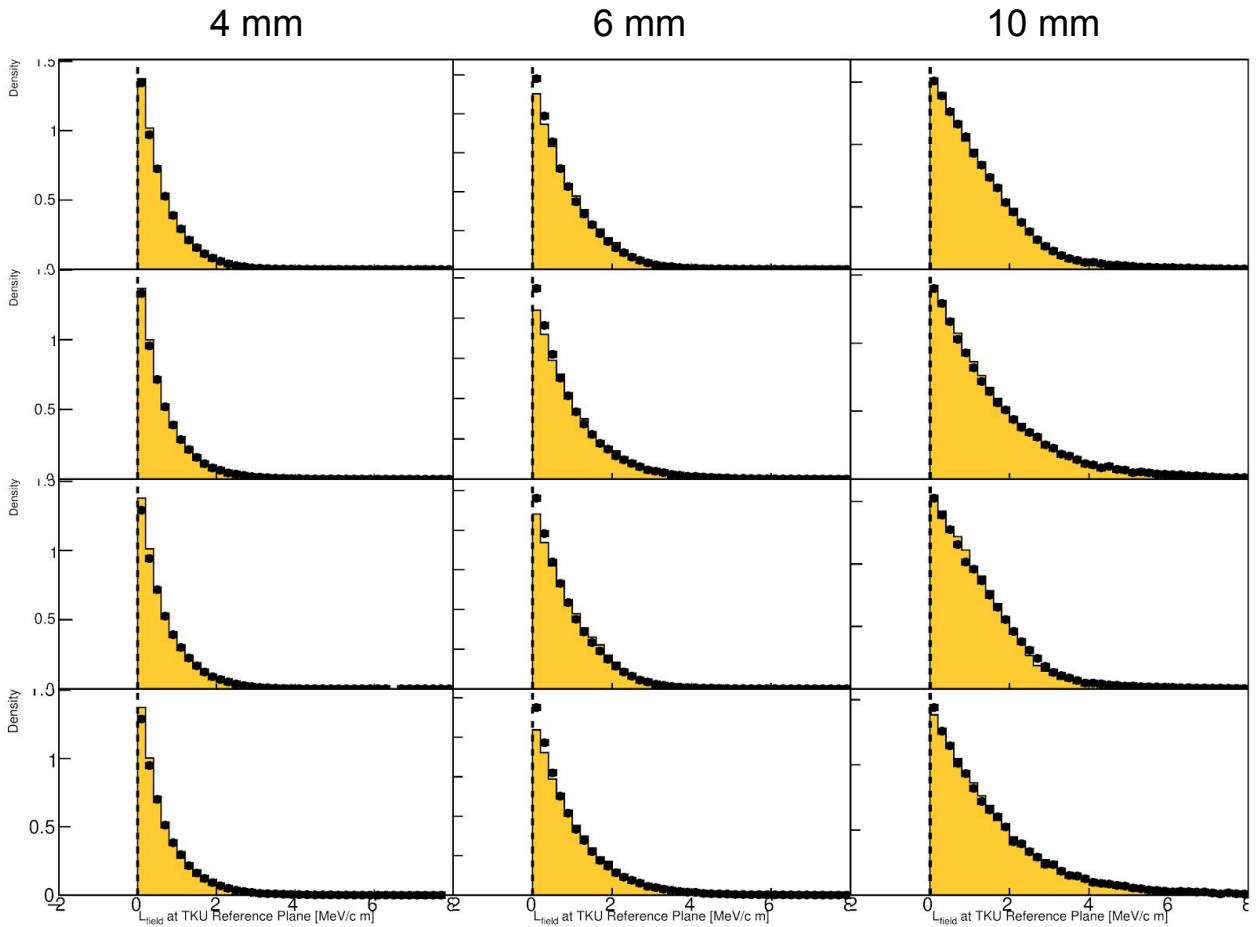
L_{kin} TKD

Imperial College London



L_{field} TKU

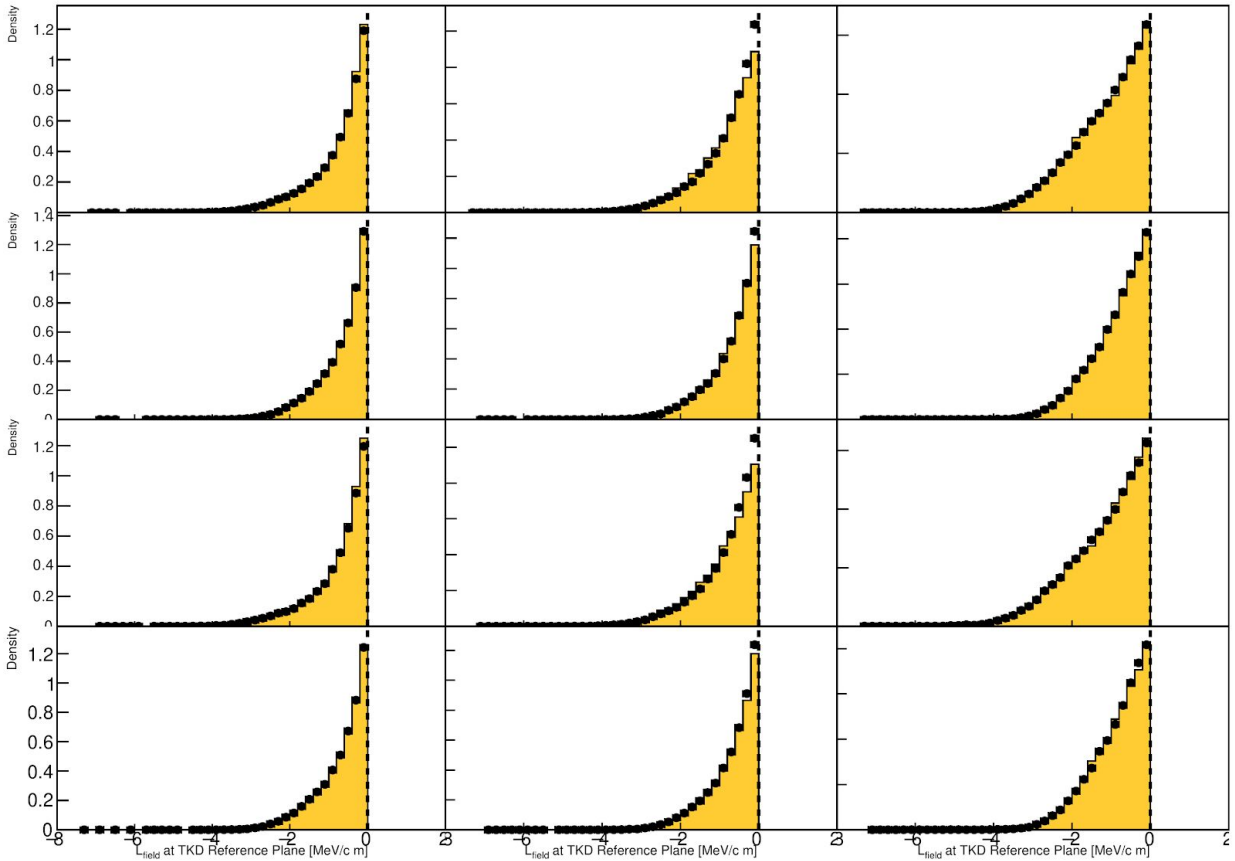
Imperial College London



L_{field} TKD

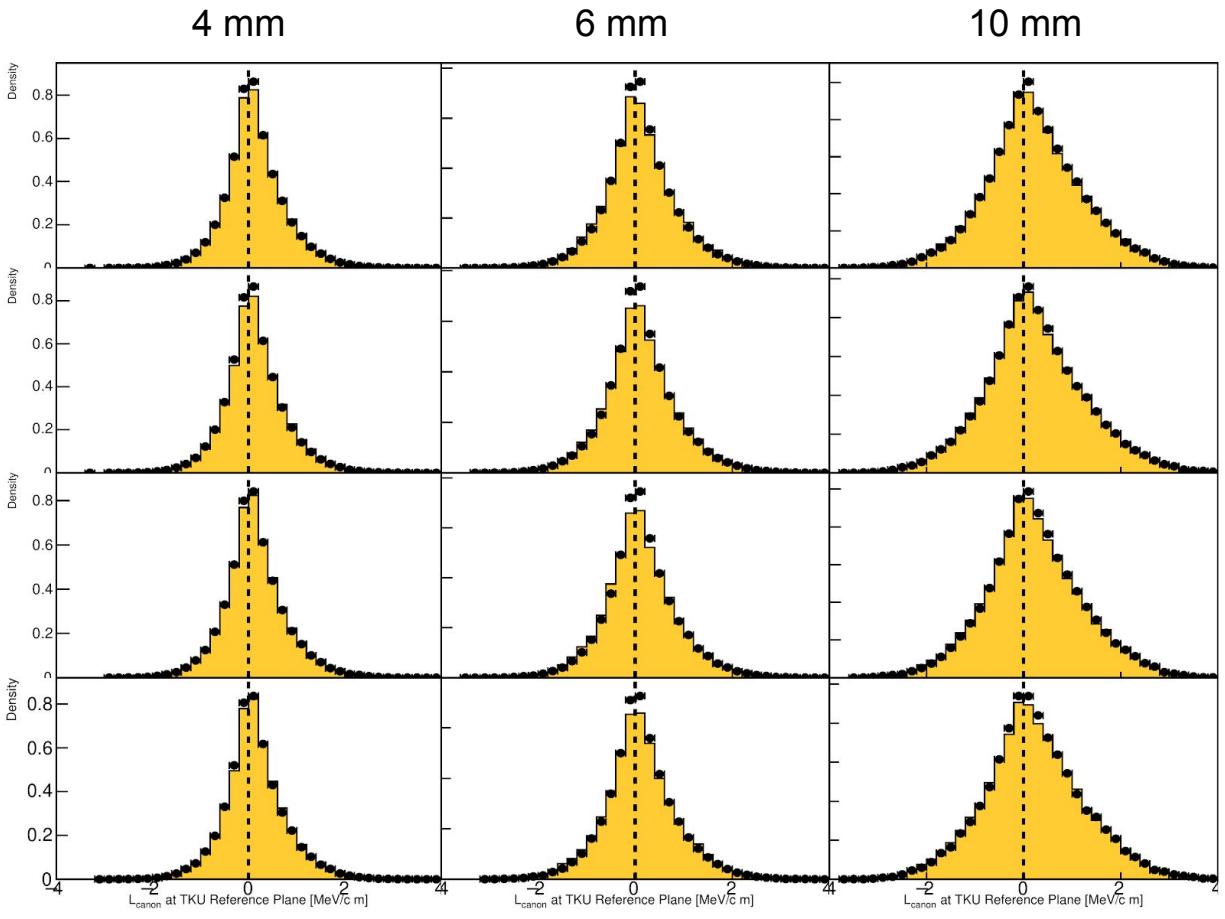
Imperial College London

	4 mm	6 mm	10 mm
Empty LH2			
LH2			
No absorber			
LiH			



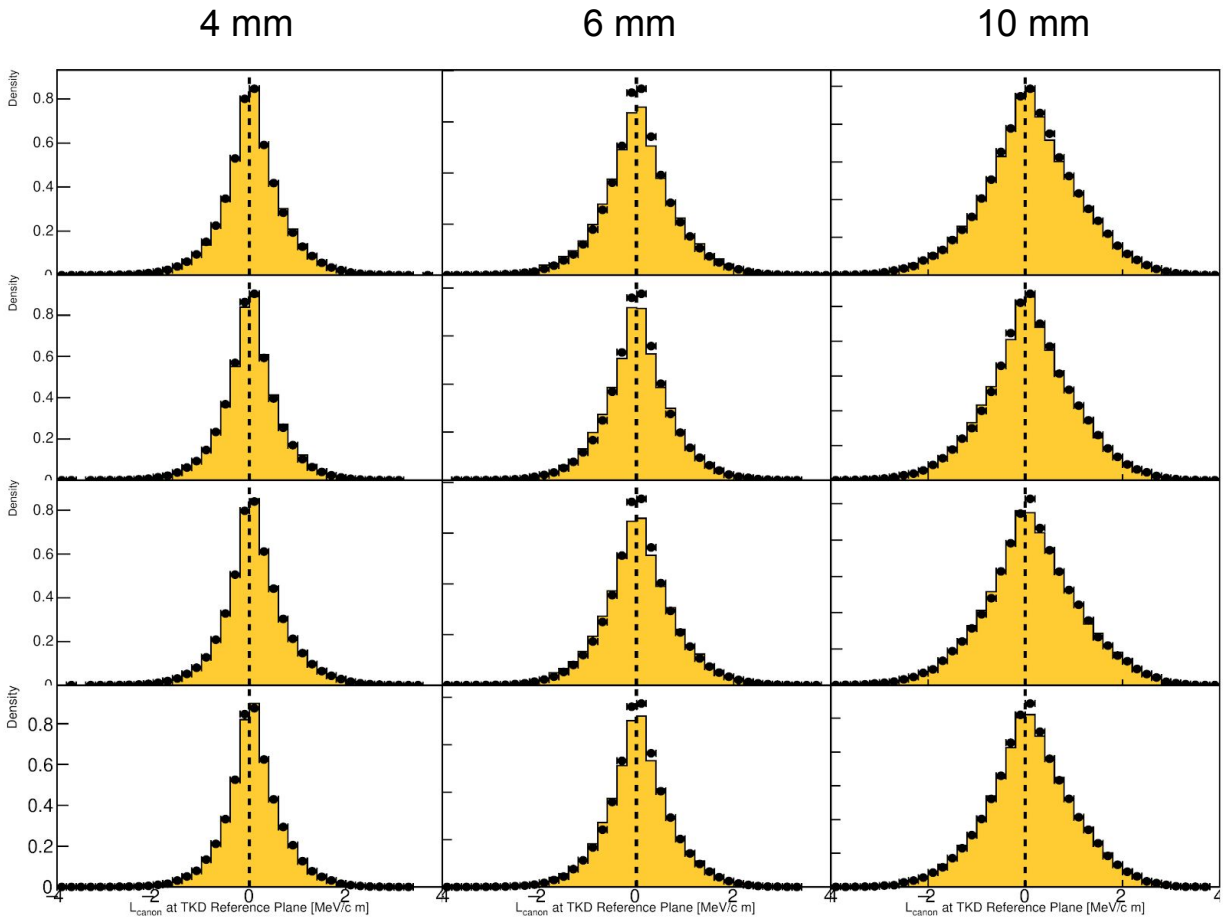
L_{canon} TKU

Imperial College London



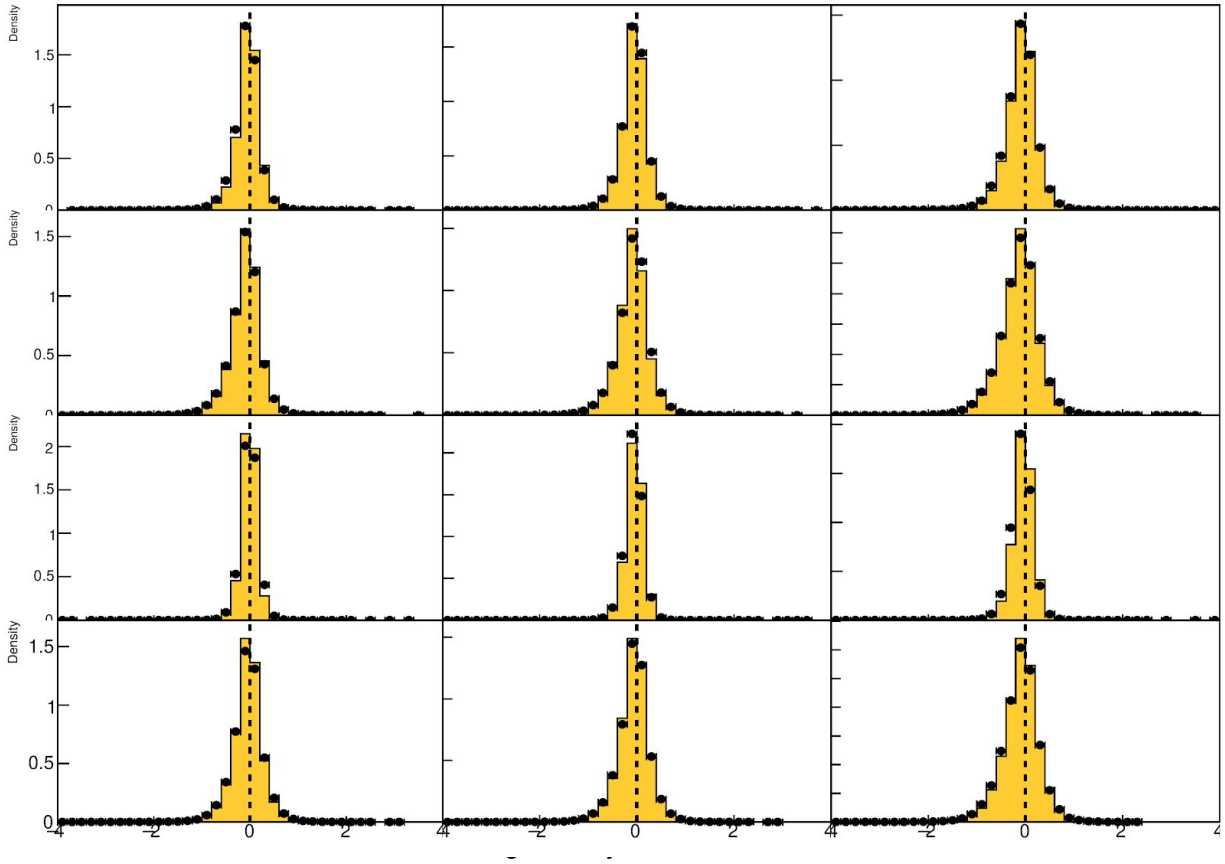
L_{canon} TKD

Imperial College London



L_{canon} (TKD) - L_{canon} (TKU)

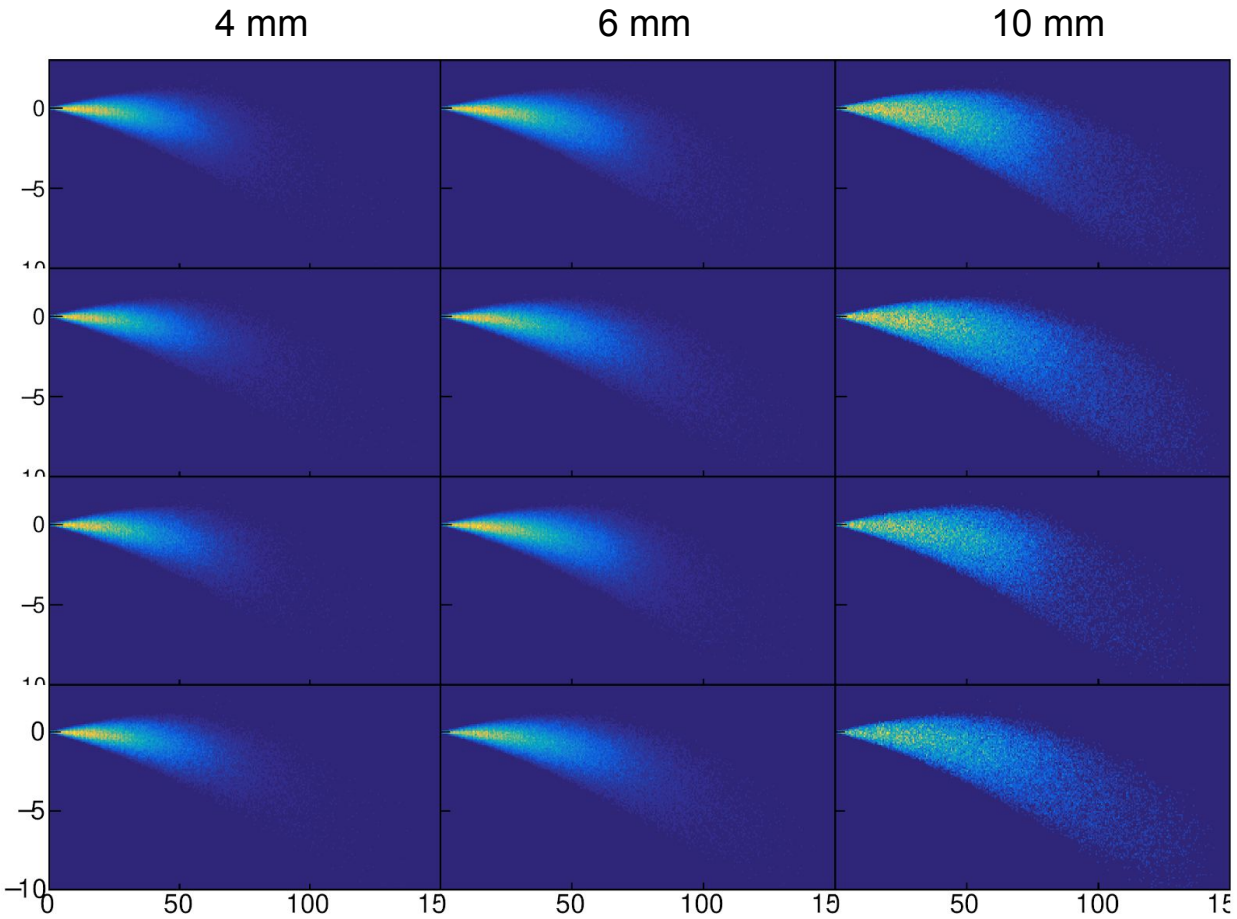
Imperial College London

	4 mm	6 mm	10 mm
Empty LH2			
LH2			
No absorber			
LiH			

2D Distributions

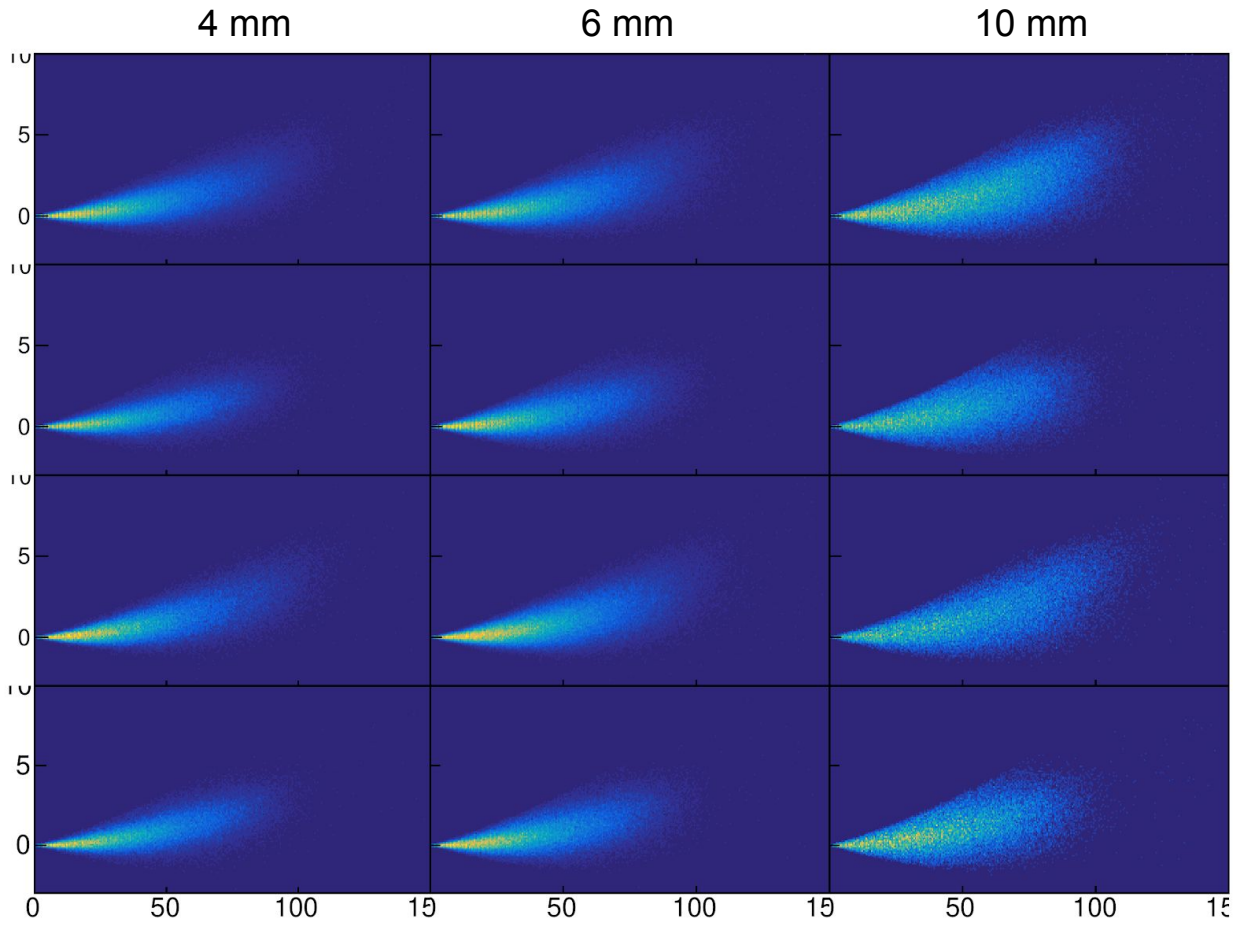
L_{kin} vs r (TKU, Data)

Imperial College London



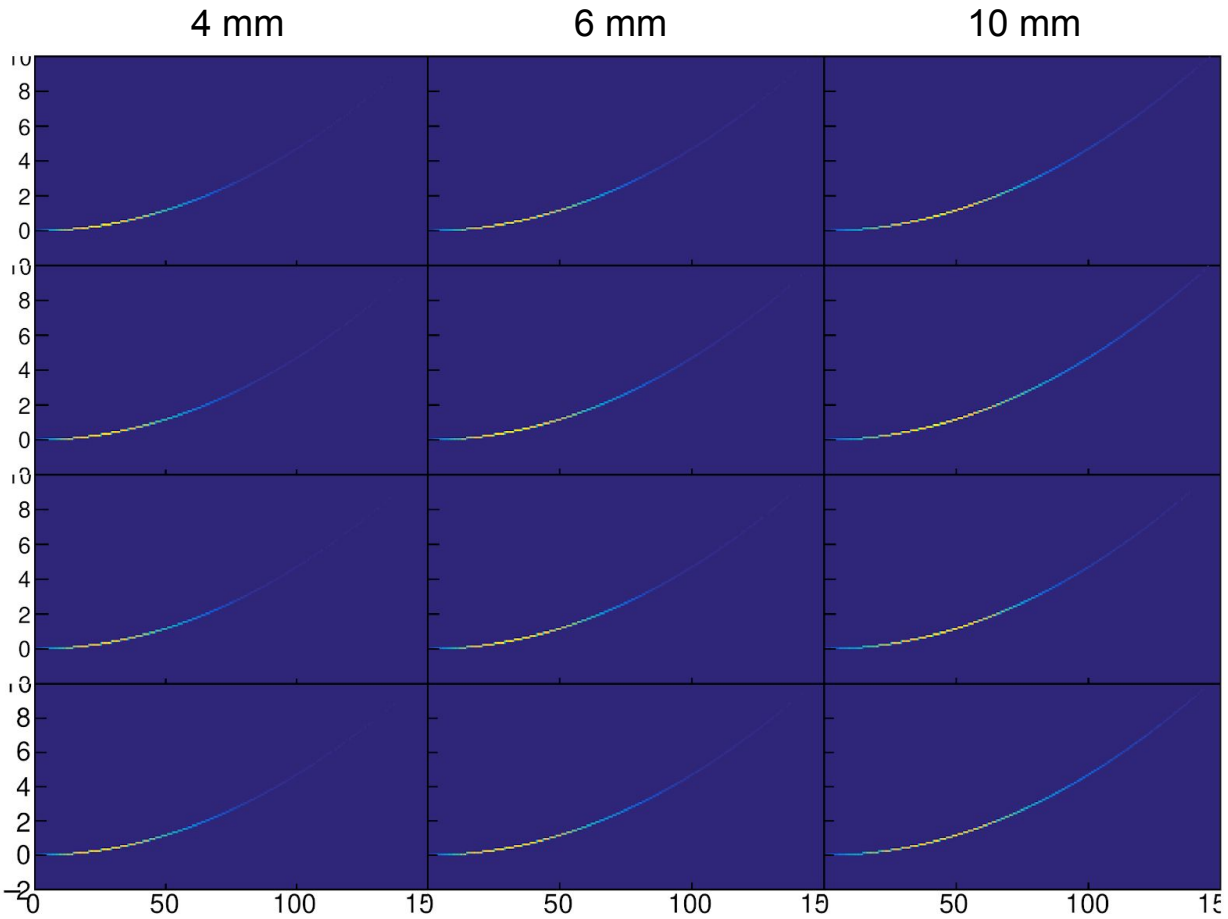
L_{kin} vs r (TKD, Data)

Imperial College London



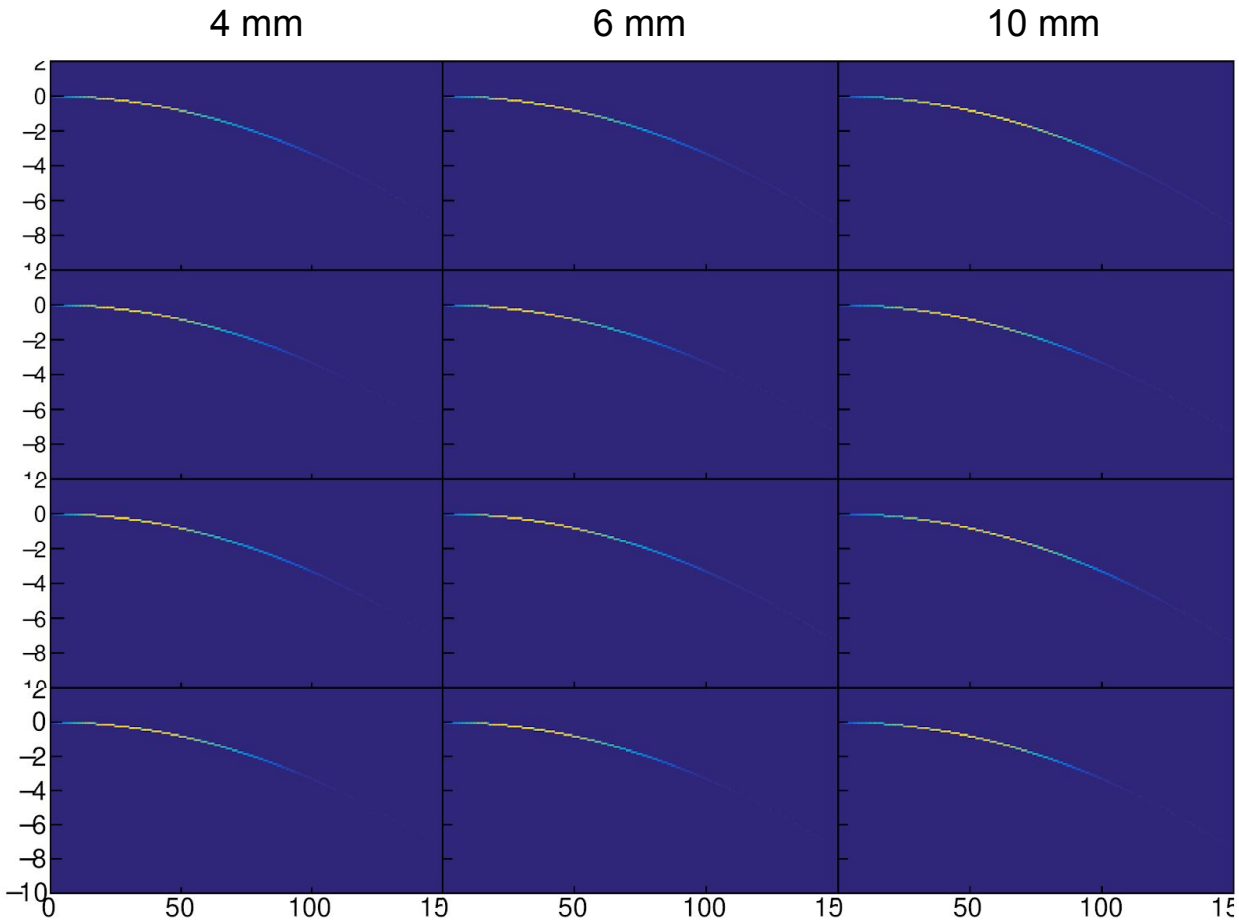
L_{field} vs r (TKU, Data)

Imperial College London



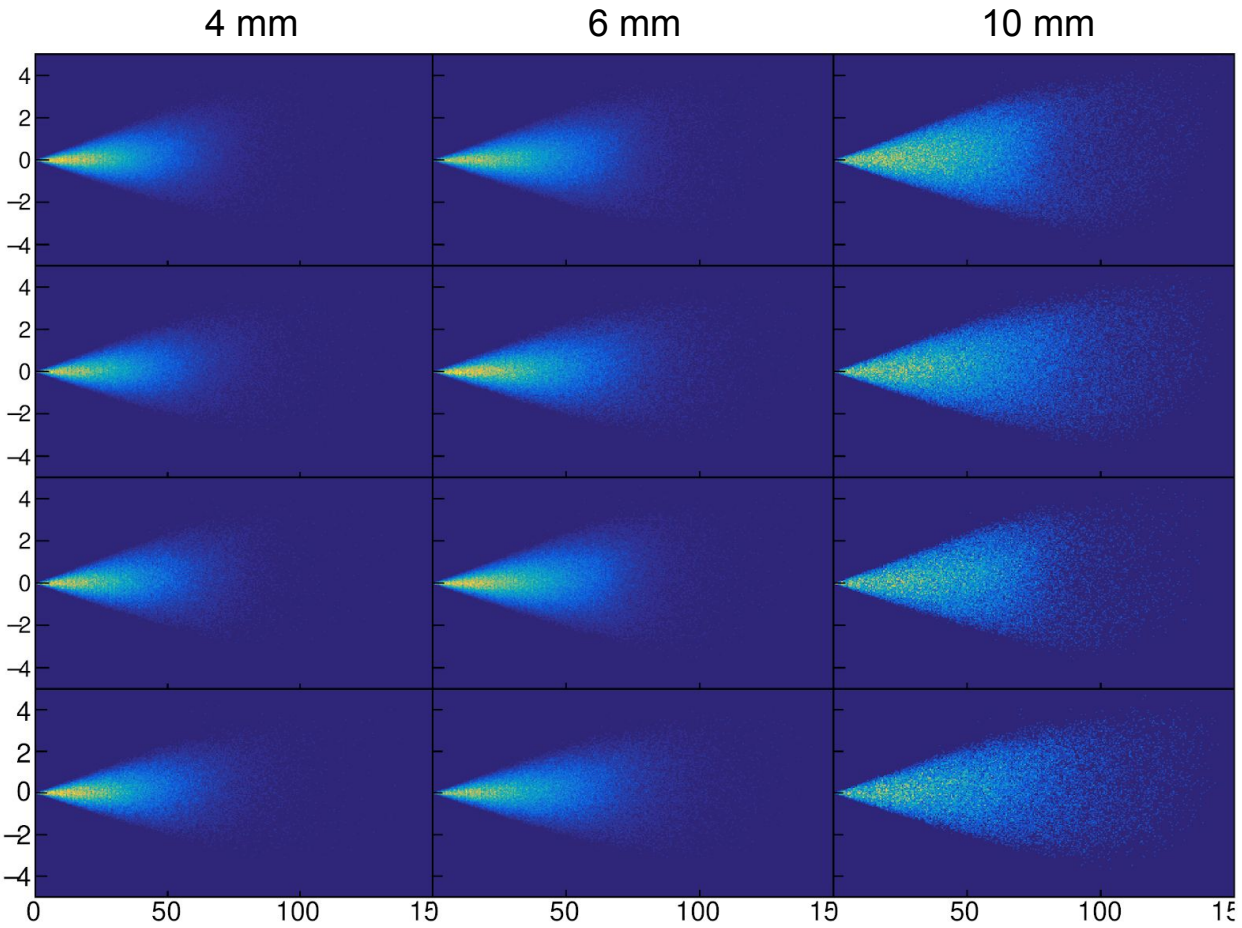
L_{field} vs r (TKD, Data)

Imperial College London



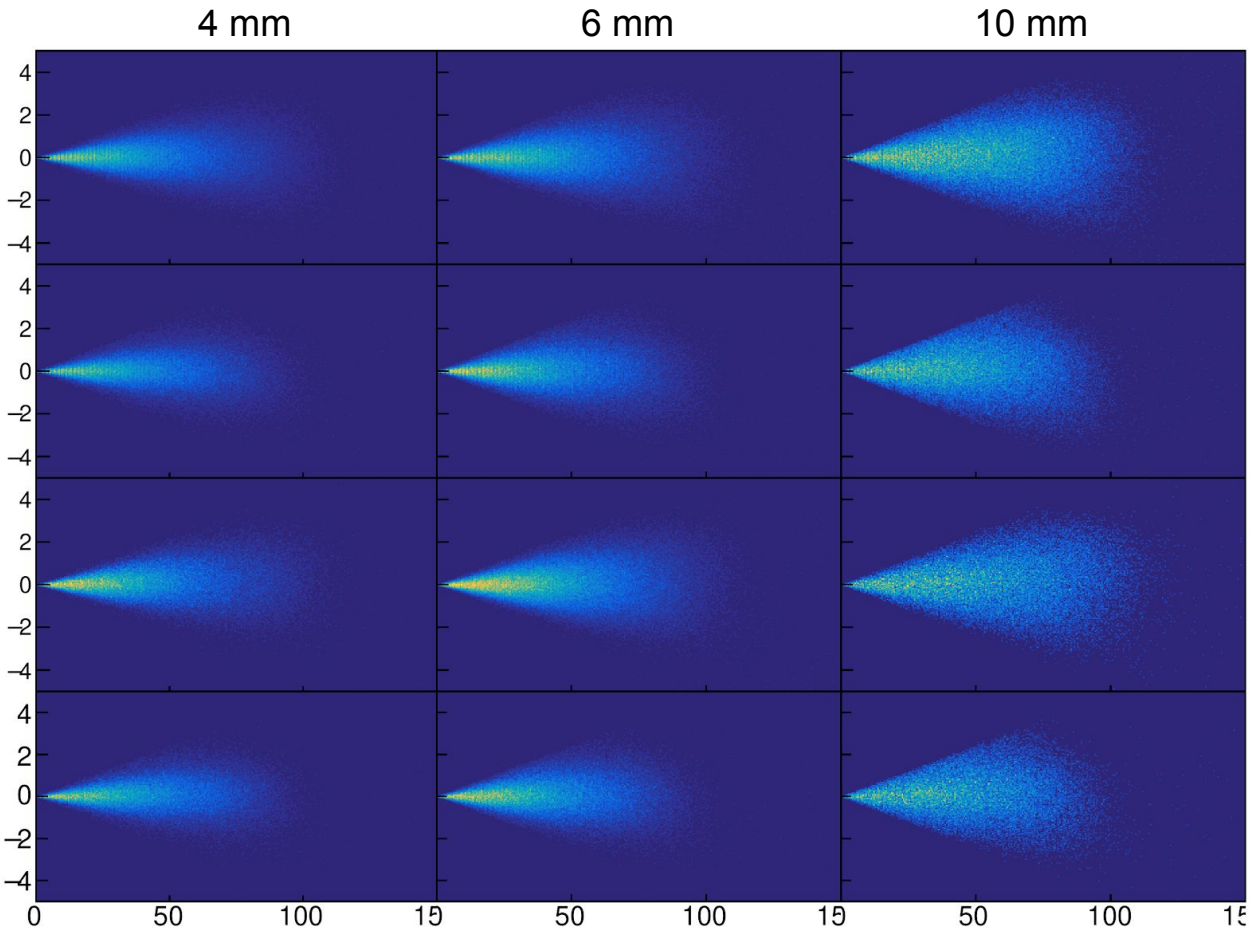
L_{canon} vs r (TKU, Data)

Imperial College London



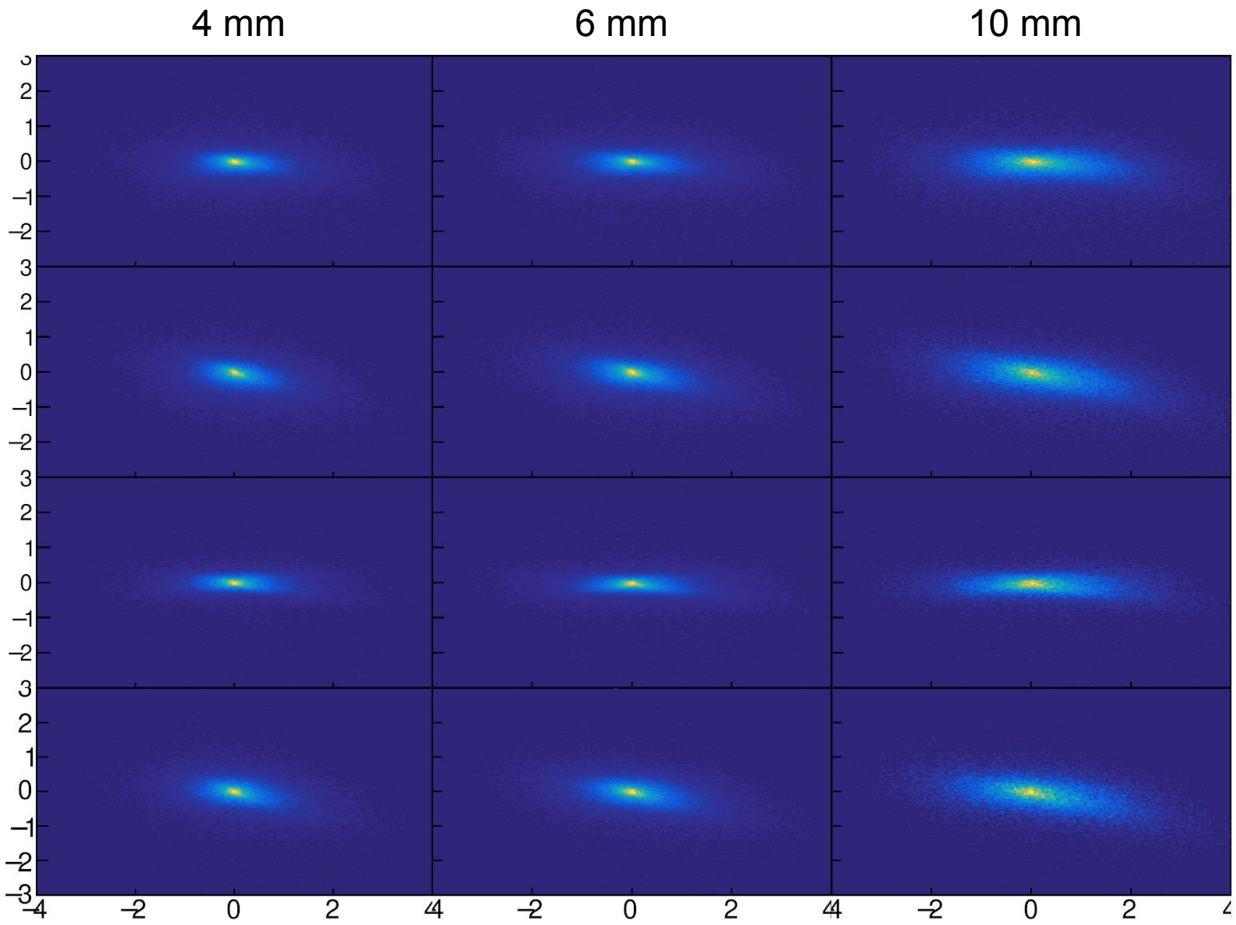
L_{canon} vs r (TKD, Data)

Imperial College London



L_{canon} (TKD) - L_{canon} (TKU) vs L_{canon} (TKU) (Data)

Imperial College London



Means evolution through cooling channel

L_{kin} mean

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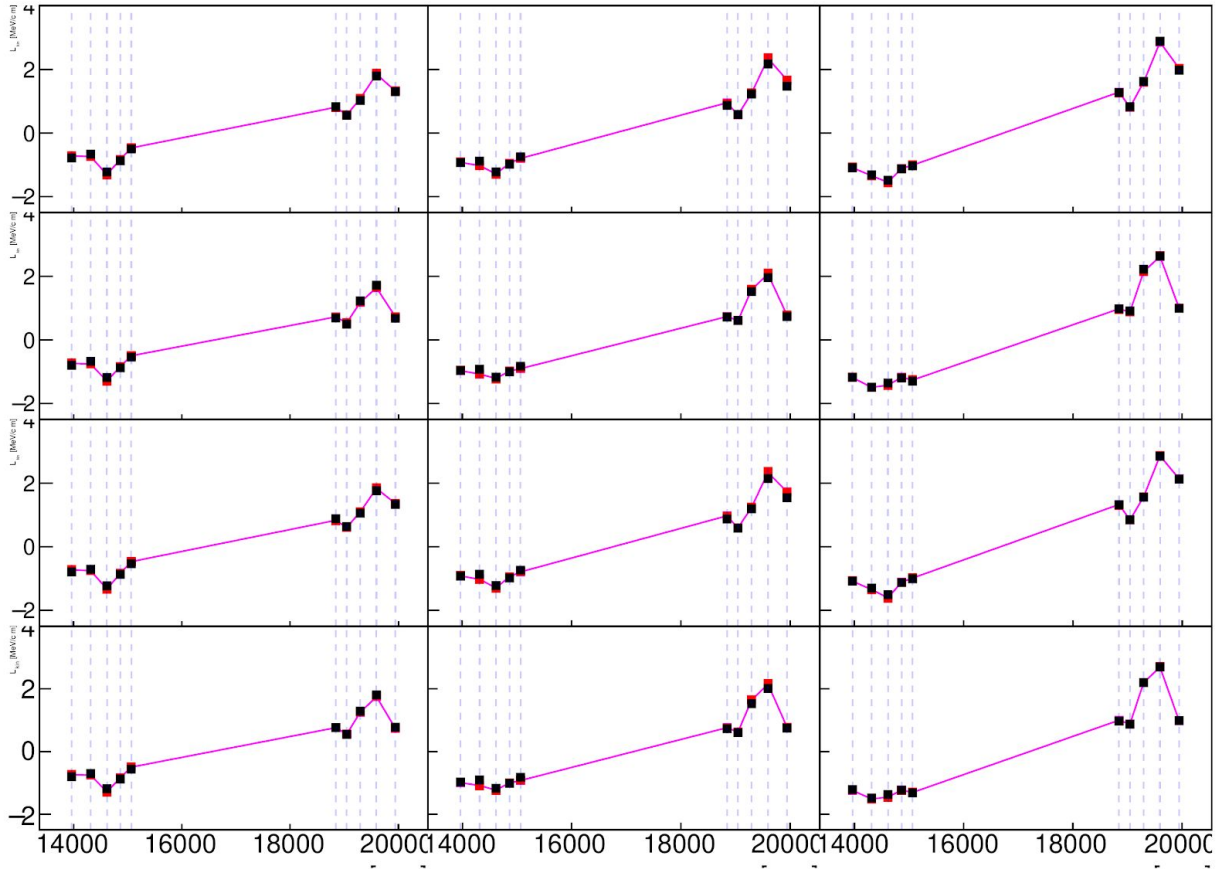
4 mm | 6 mm | 10 mm

Empty LH2

LH2

No absorber

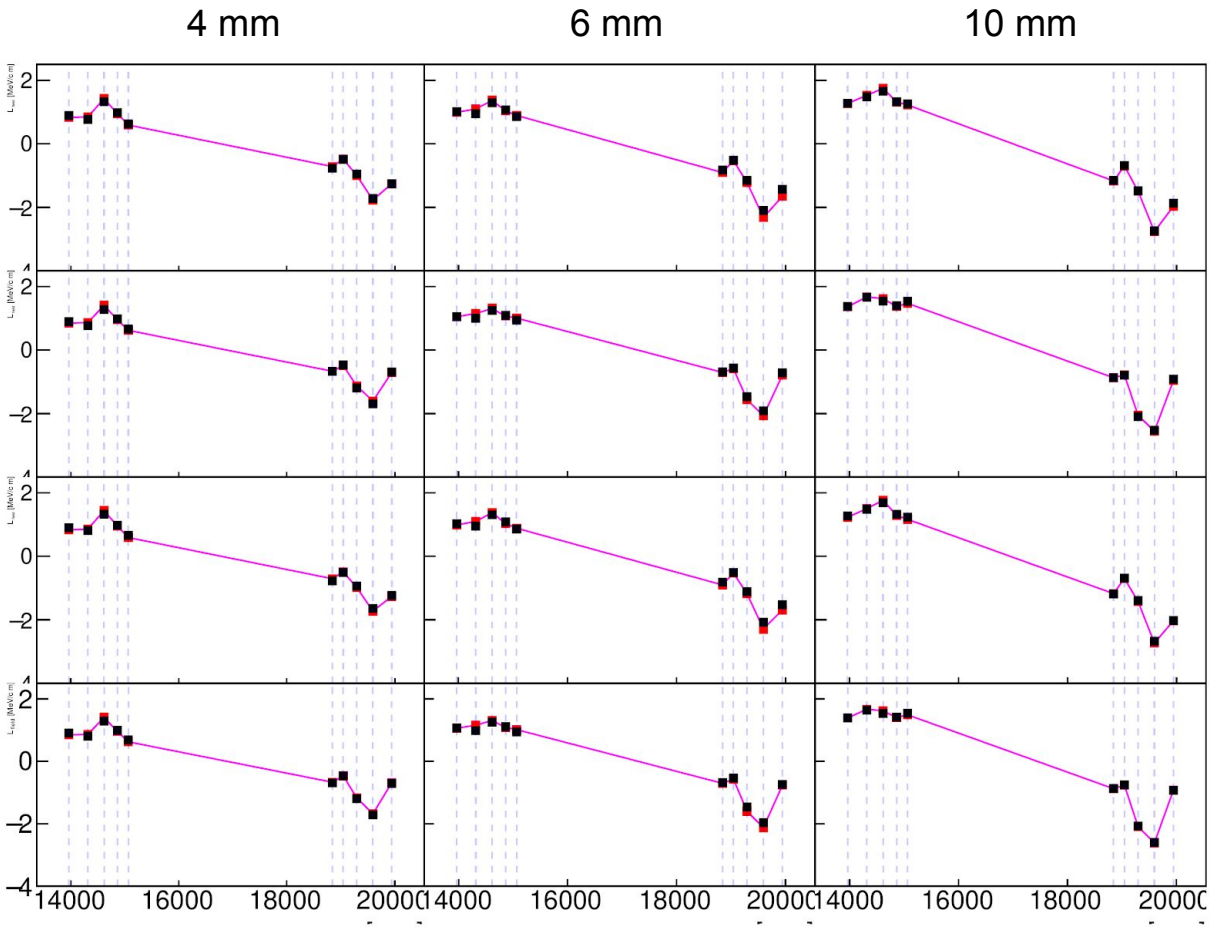
LiH



DATA
MC RECO
MC TRUTH

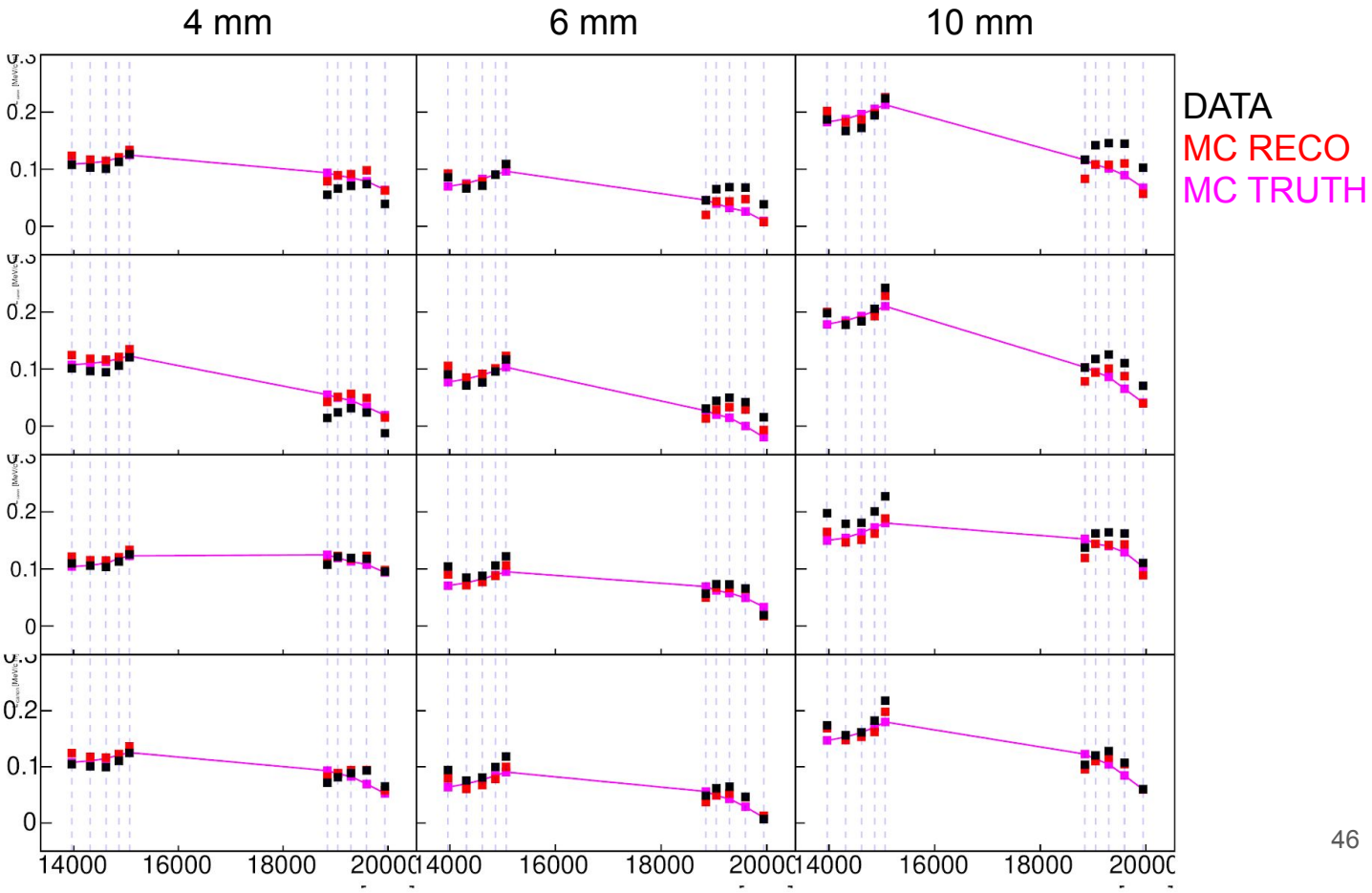
L_{field} mean

Imperial College London



L_{canon} mean

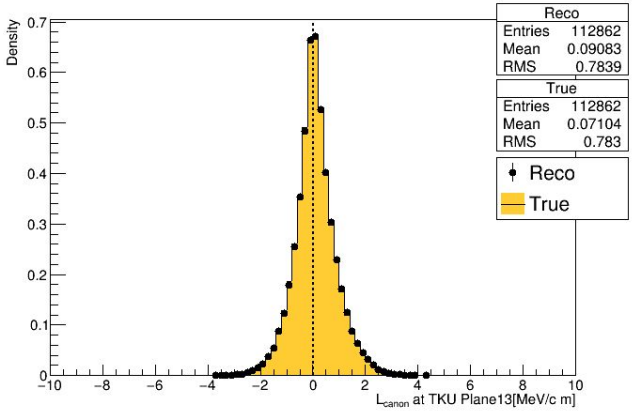
Imperial College London

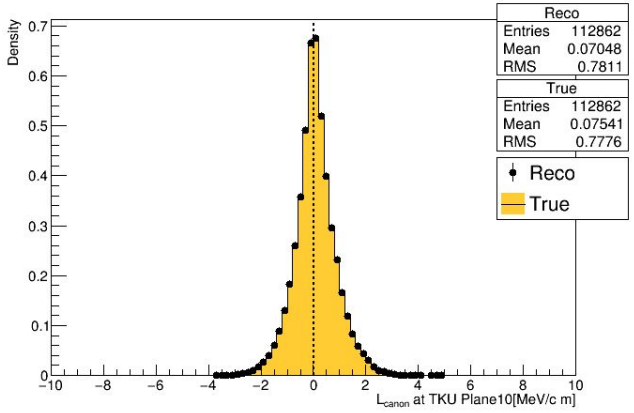


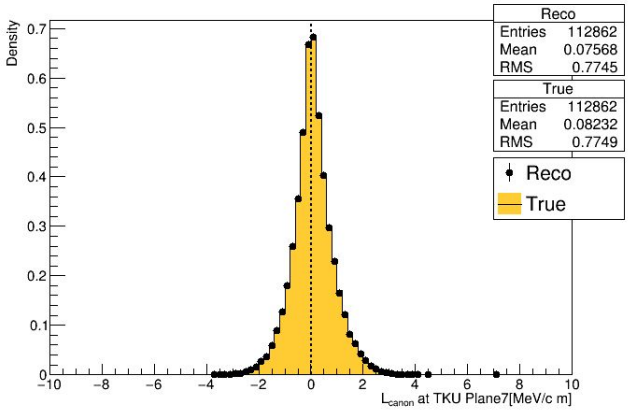
MC: RECO VS TRUE

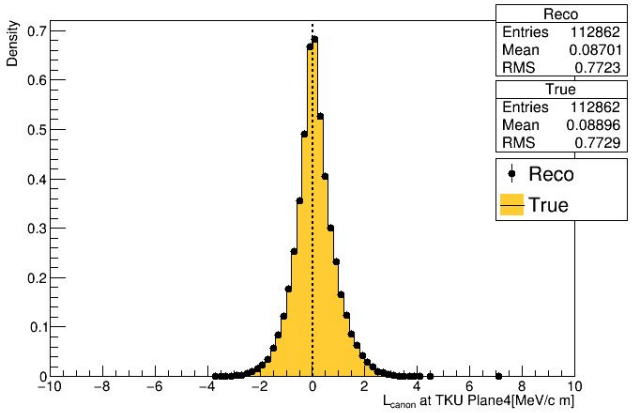
(No absorber 6-140)

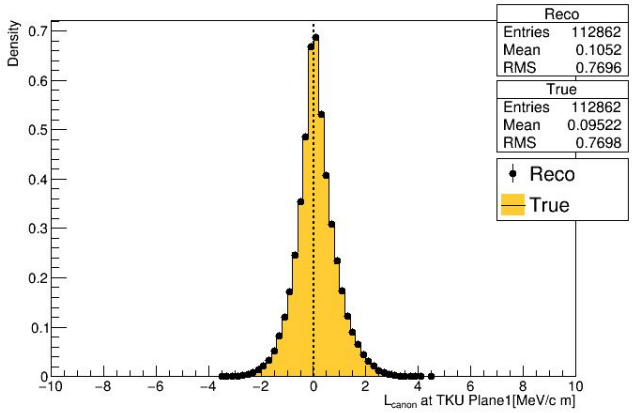
L_{canon} in TKU stations











L_{canon} in TKD stations

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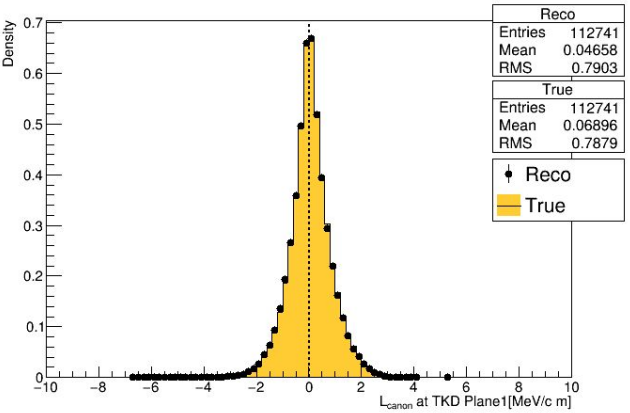
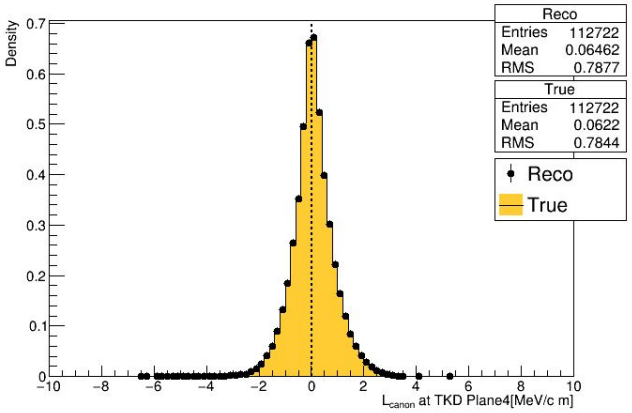
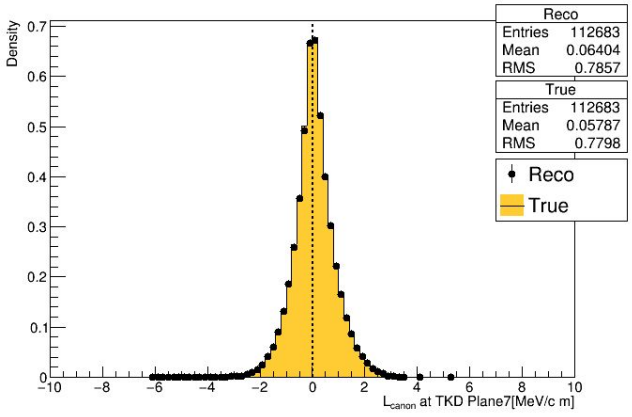
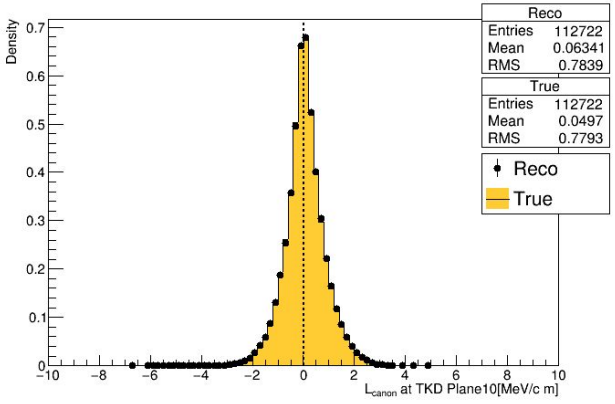
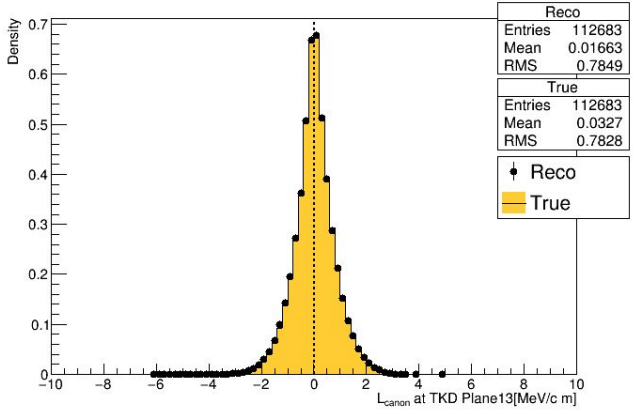


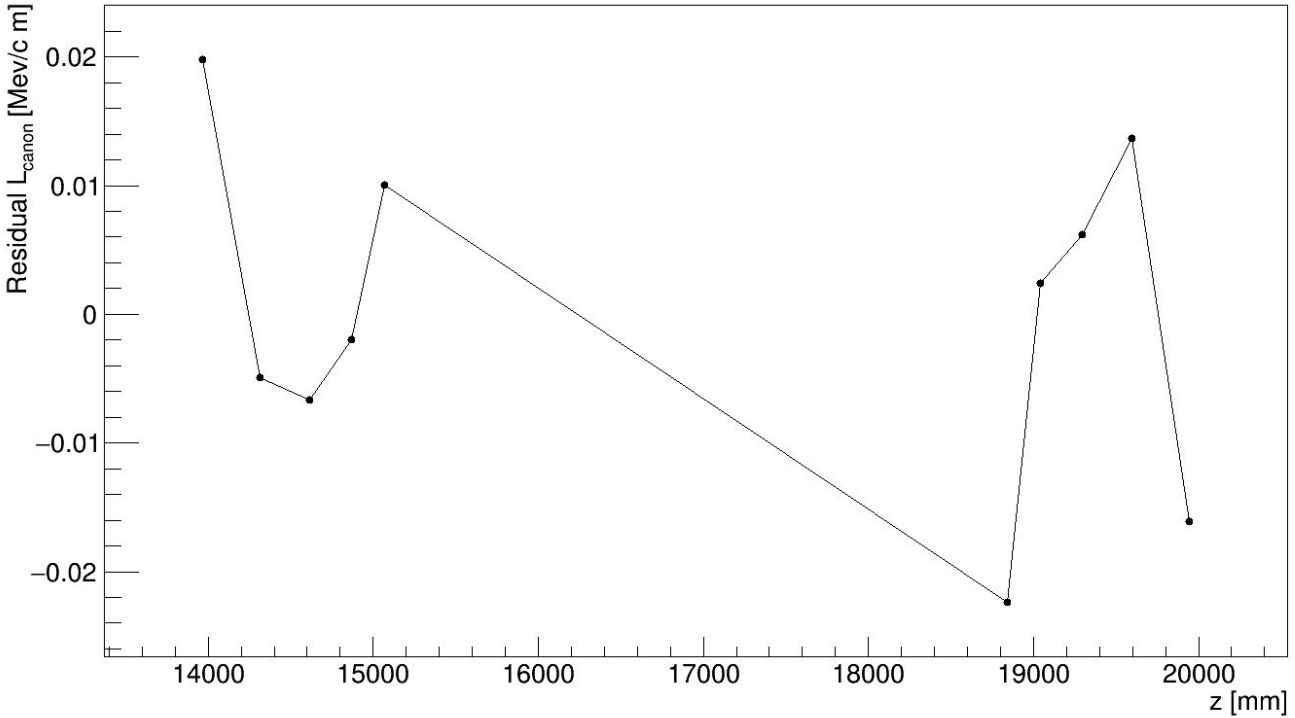




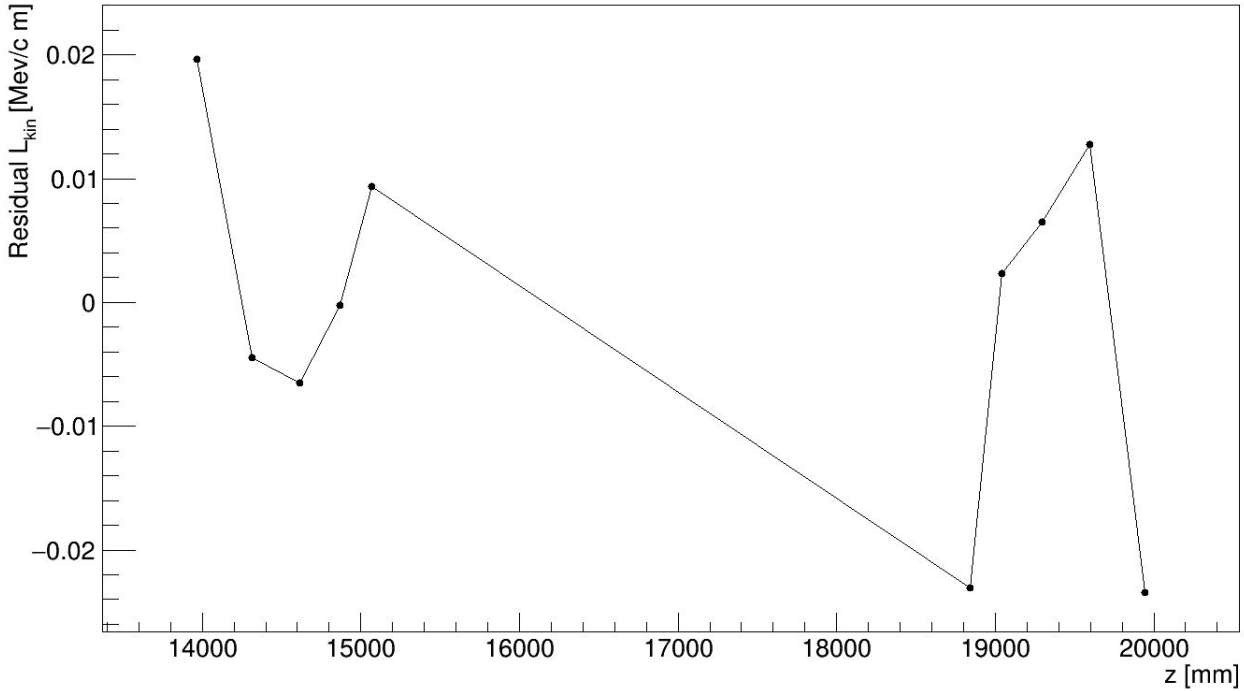




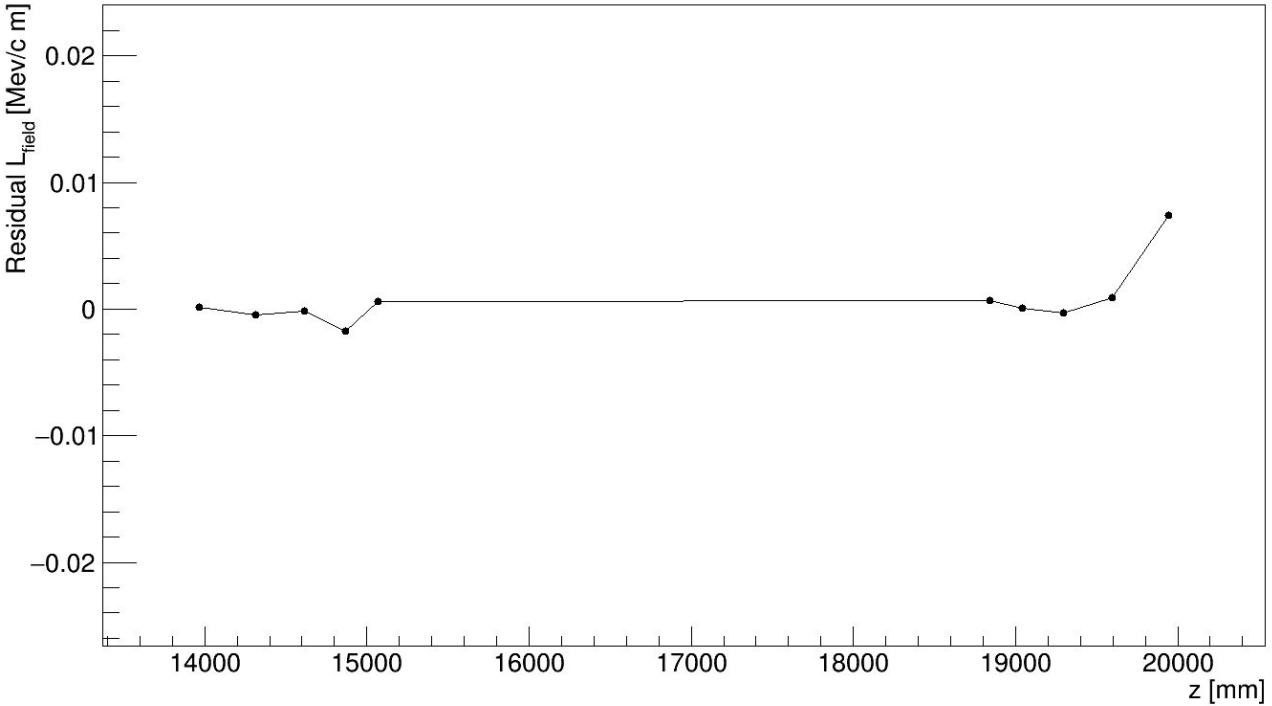
L_{canon} mean residual



L_{kin} mean residual



L_{field} mean residual



Canonical angular momentum - outstanding issues

- Detector effects correction
- Systematics study
- Transmission effects

BACKUP

Updated MC vs Data: 6-140 Cuts

TKU momentum

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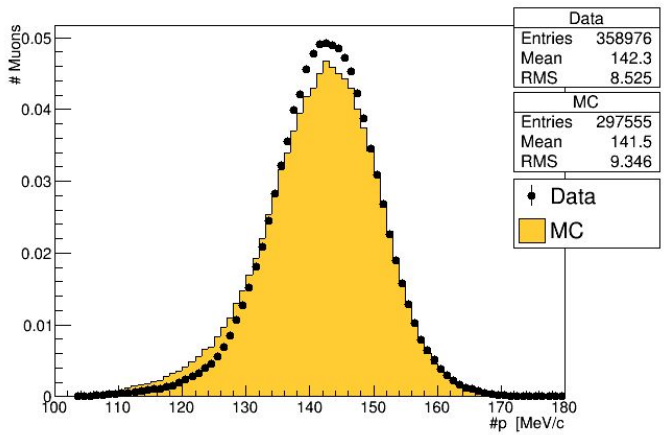
No abs



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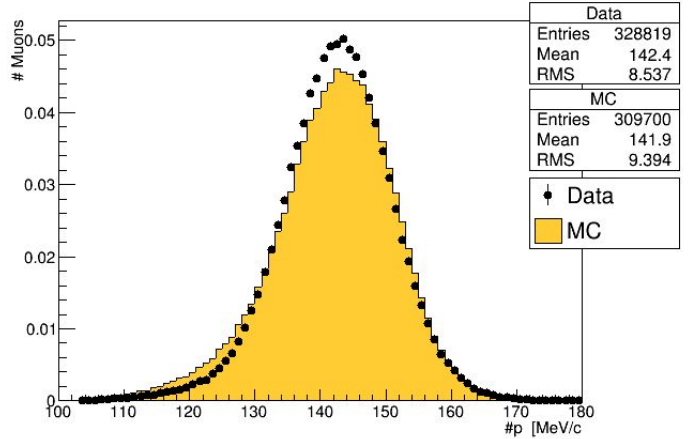
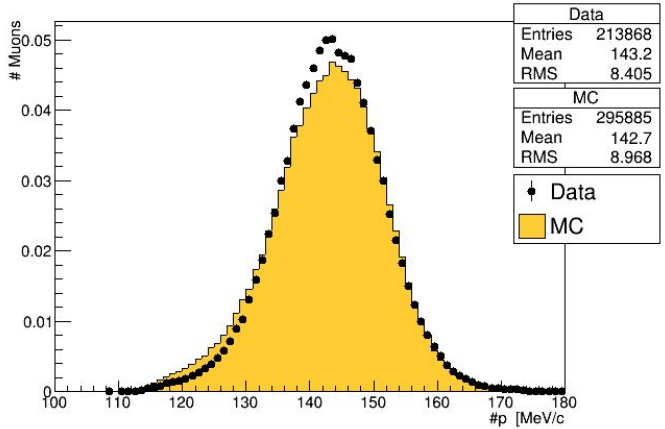


LiH



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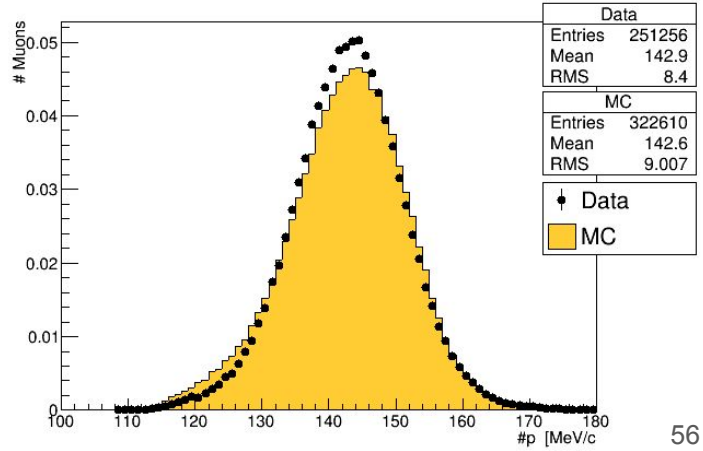

TOF01 time

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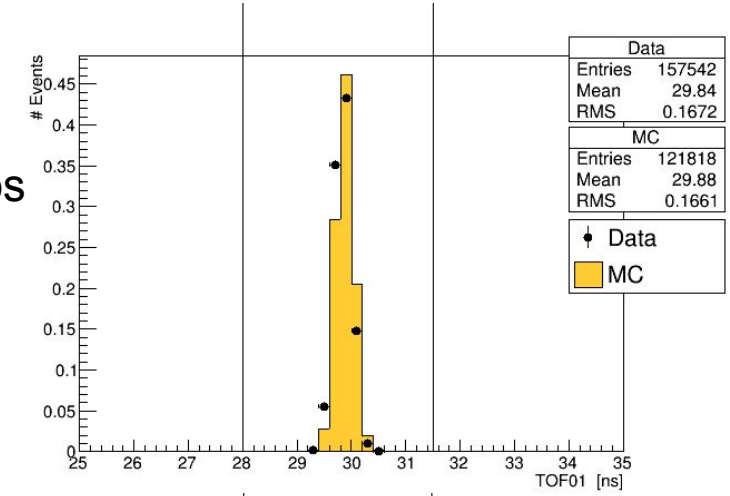
No abs



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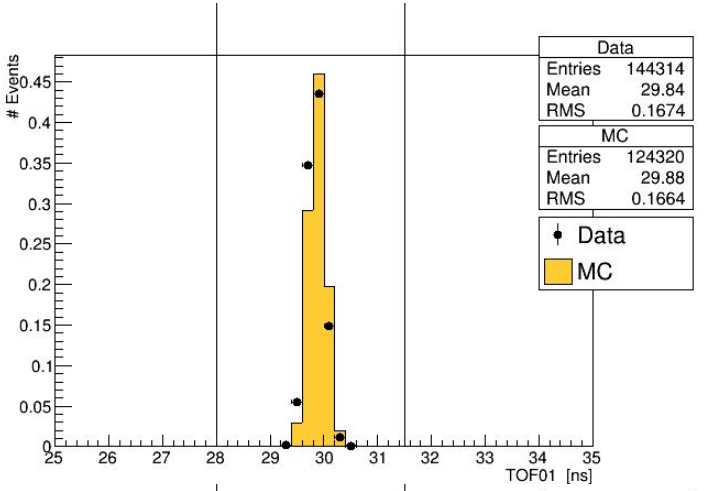

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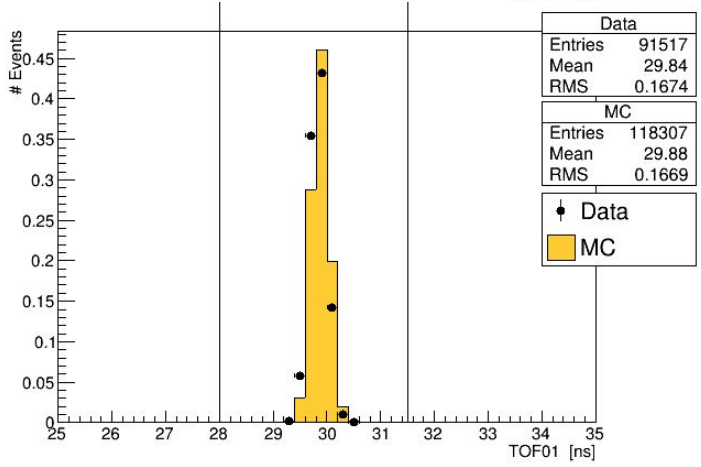

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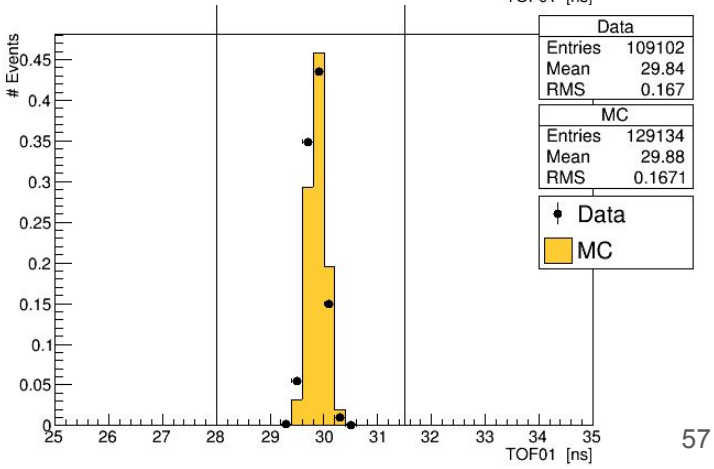

$p_{TOF01} - p_{TKU}$

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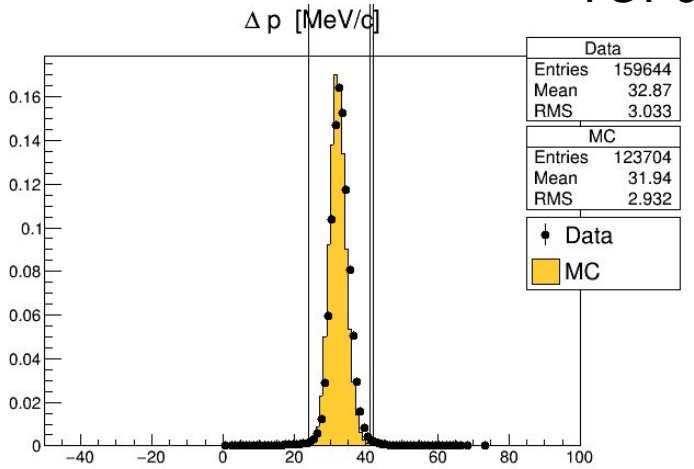
No abs



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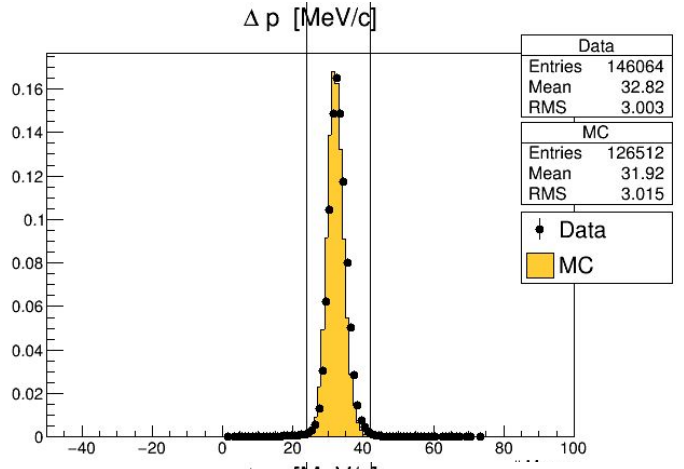
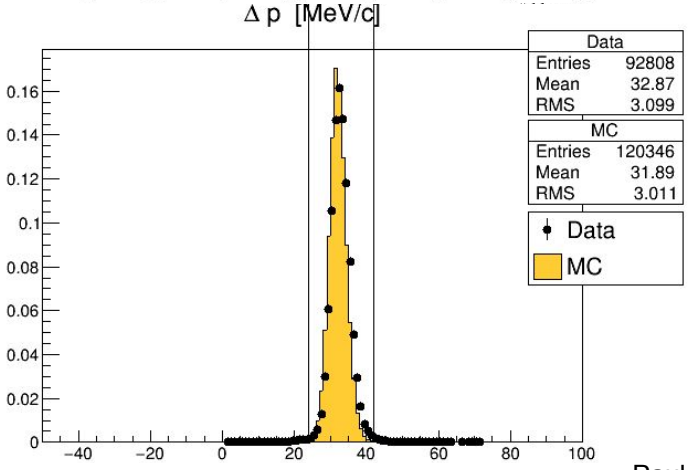


LiH



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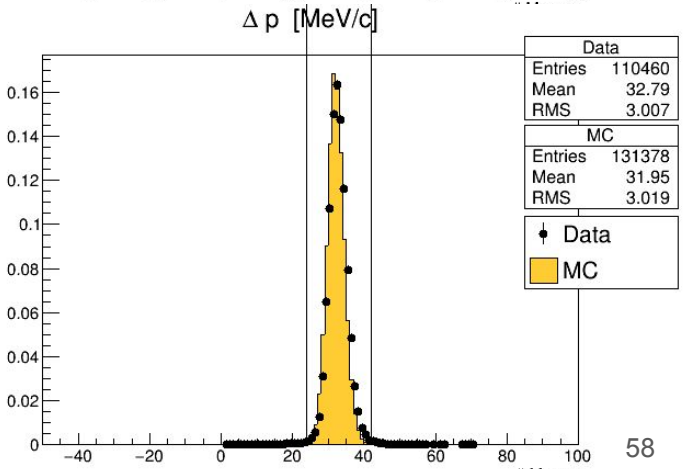

TKU fiducial cut

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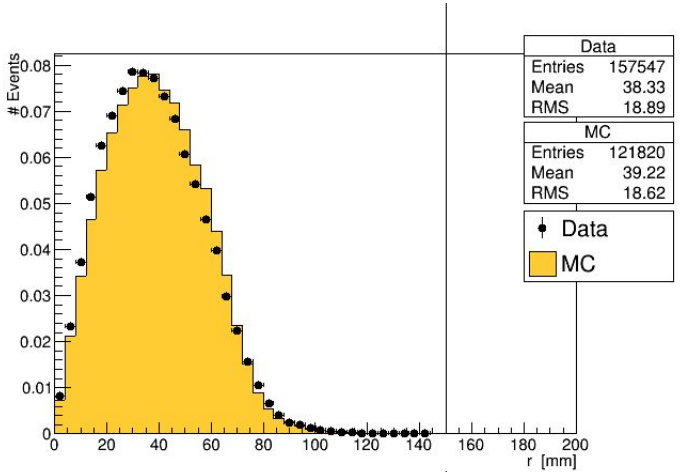
No abs



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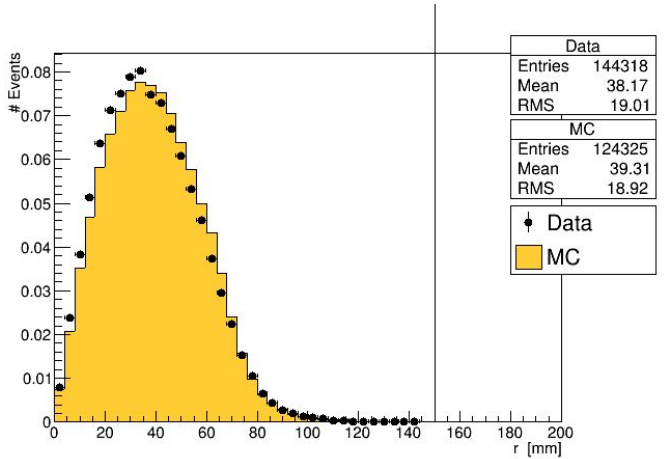

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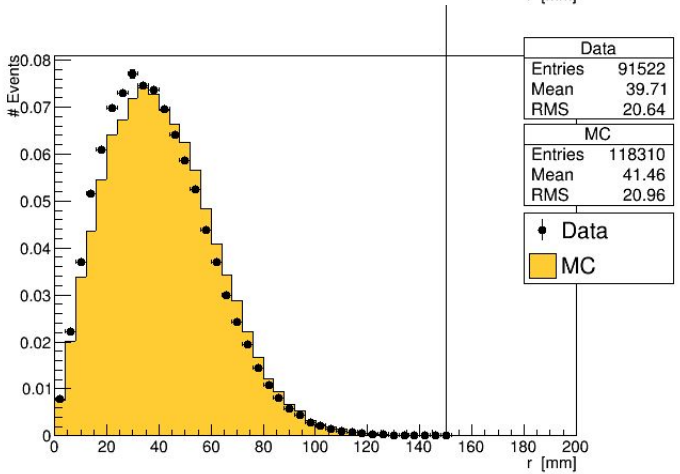

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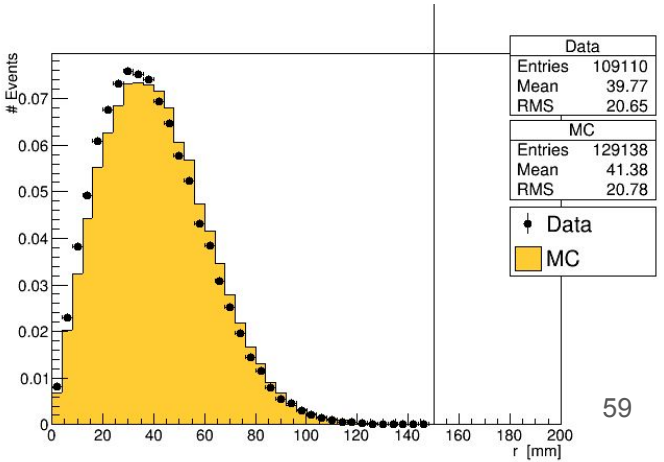
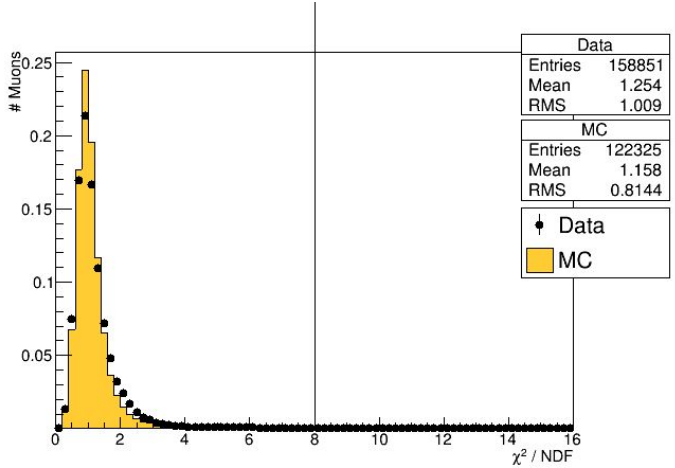


ogdan Jurj

χ^2 / ndf TKU

Imperial College London

No abs



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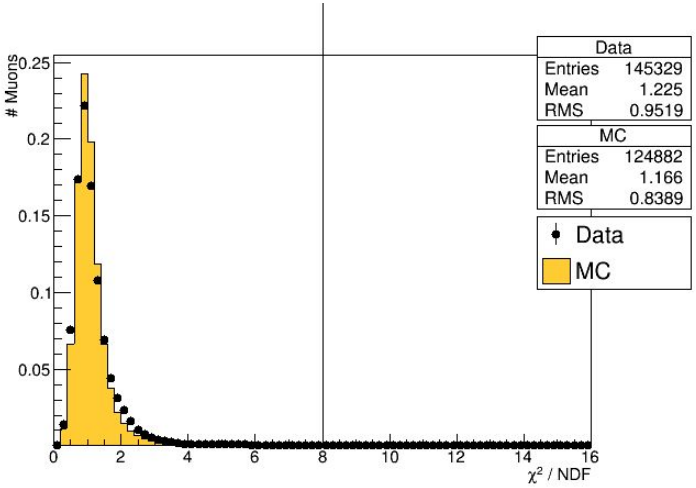

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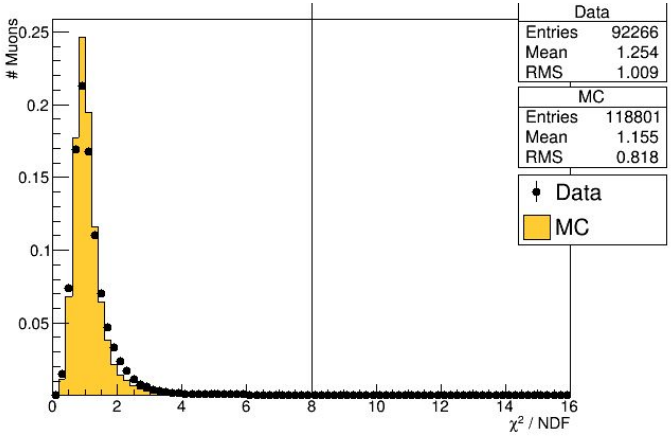

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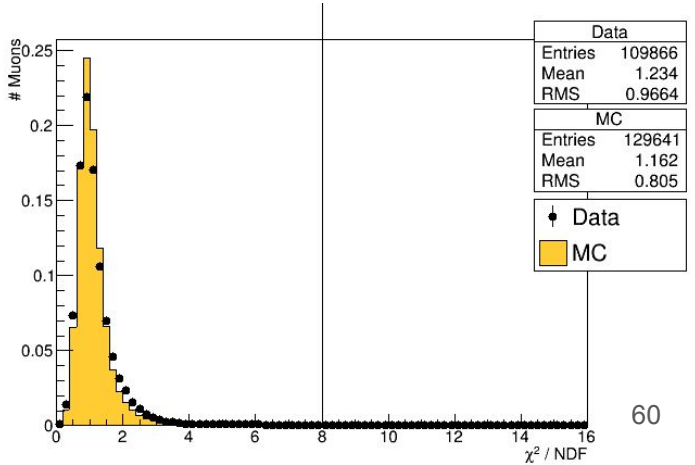

TKD momentum

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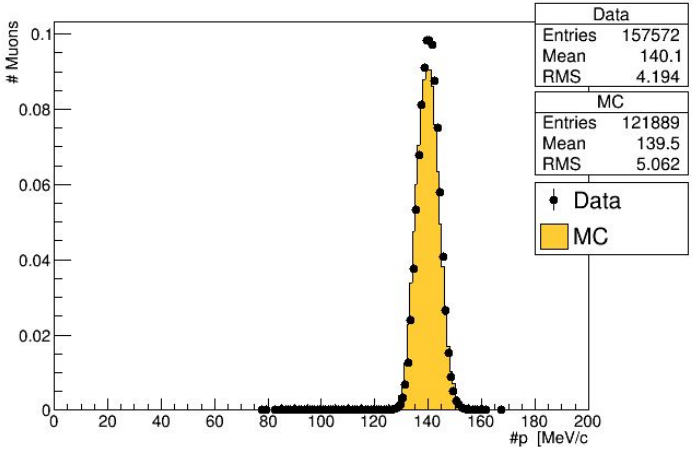
No abs



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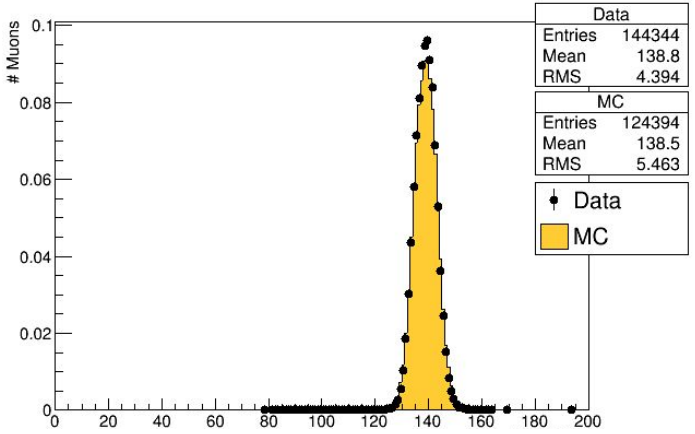

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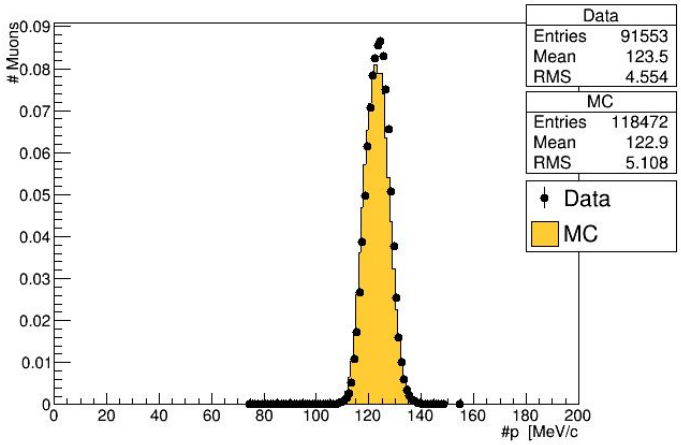

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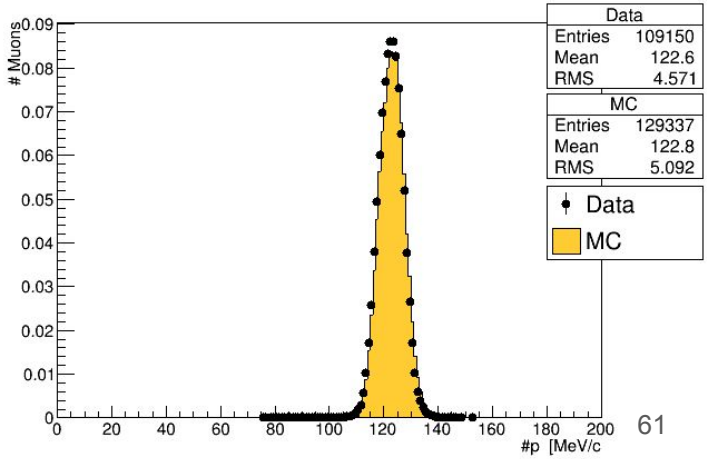

TKD fiducial cut

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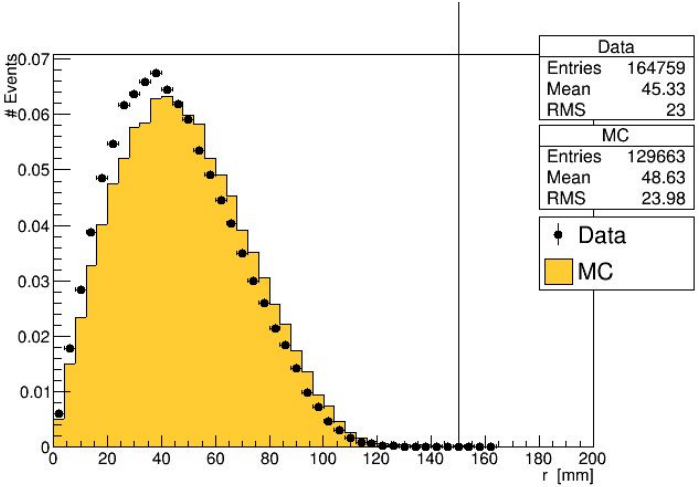
No abs



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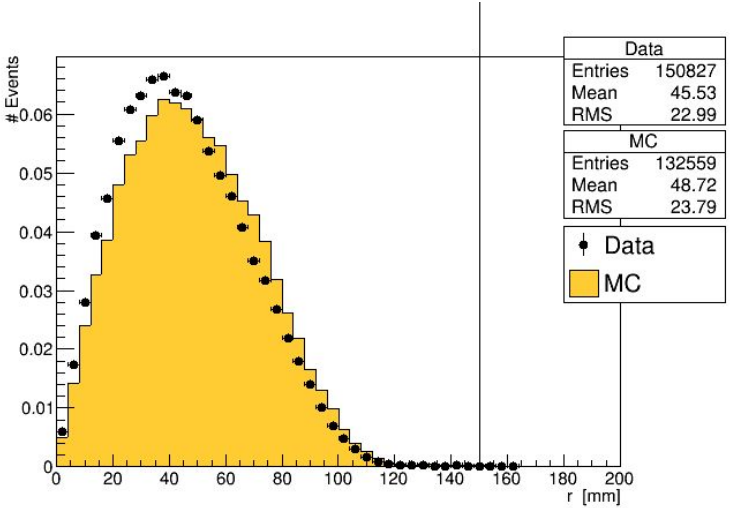

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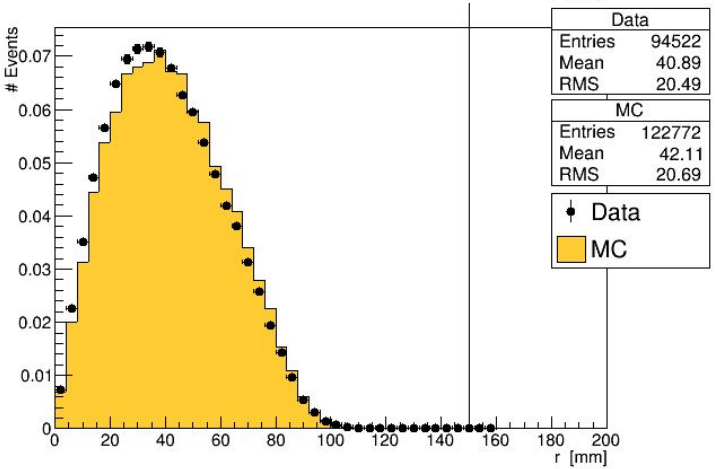

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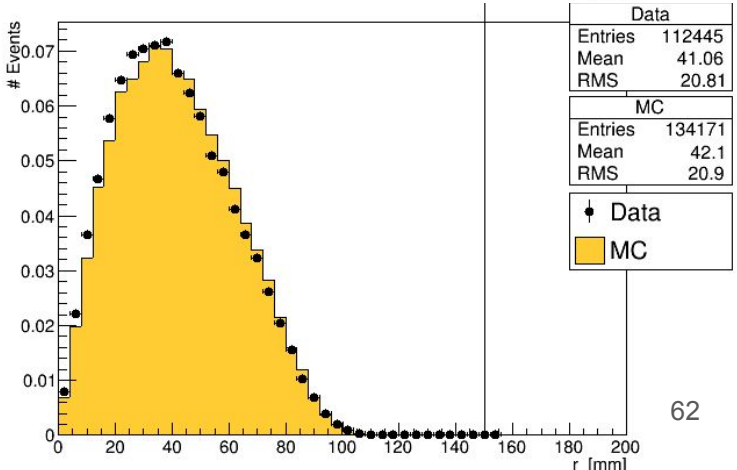

χ^2 / ndf TKD

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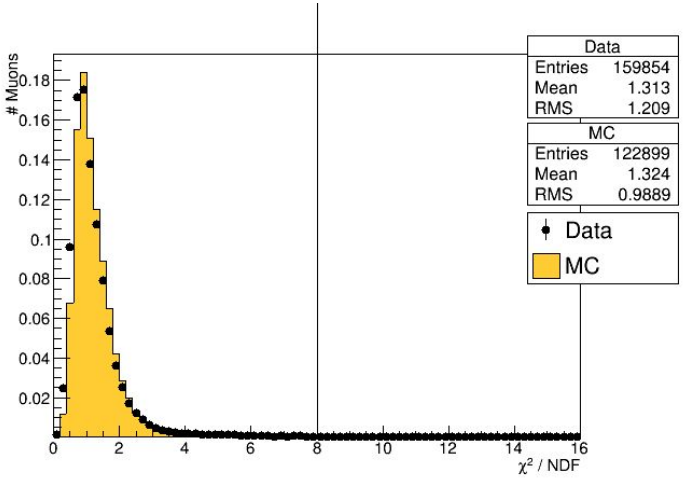

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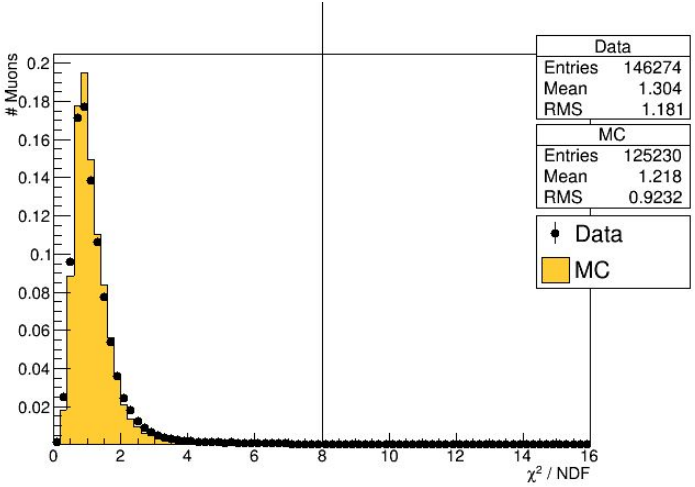

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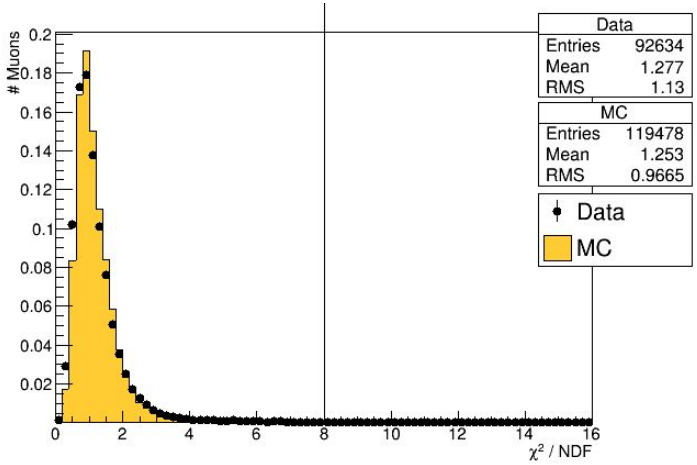

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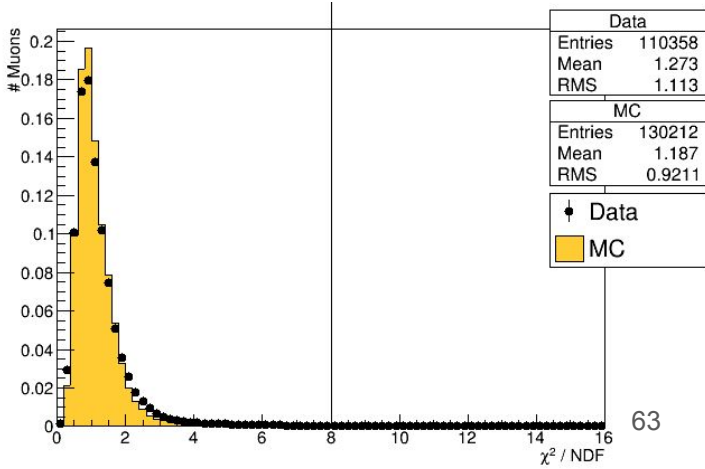
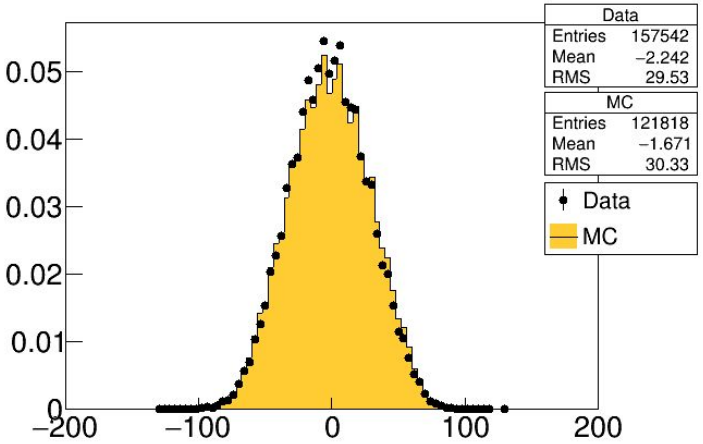


Parent distributions phase space

X TKU

No abs



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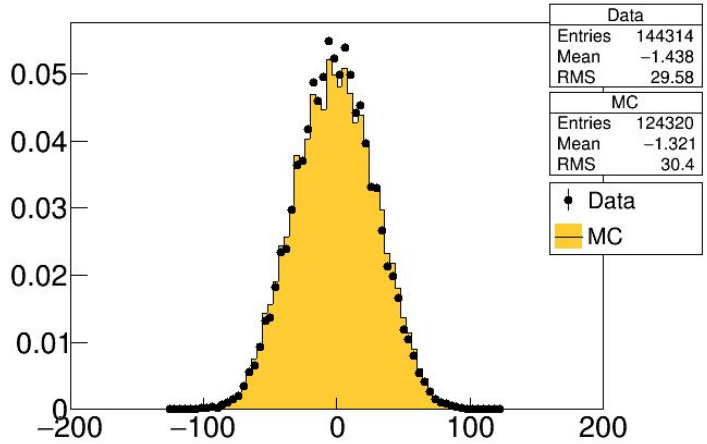

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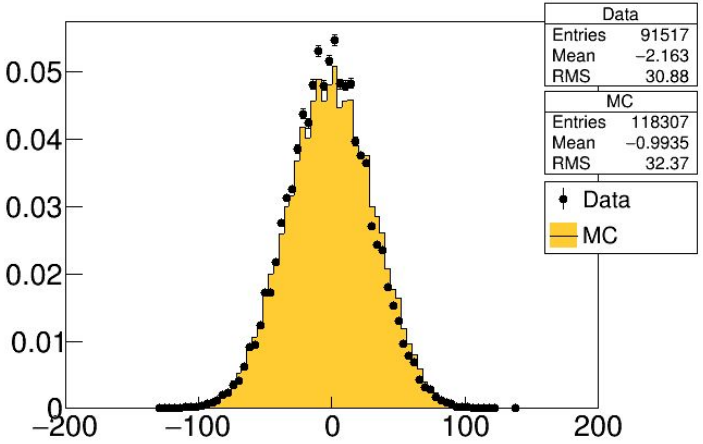

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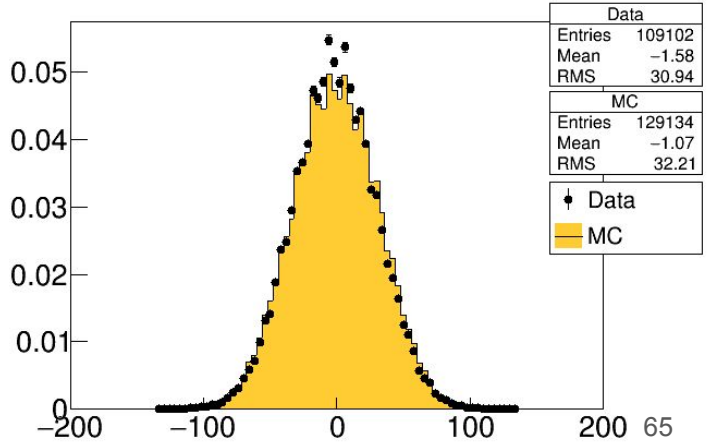

X TKD

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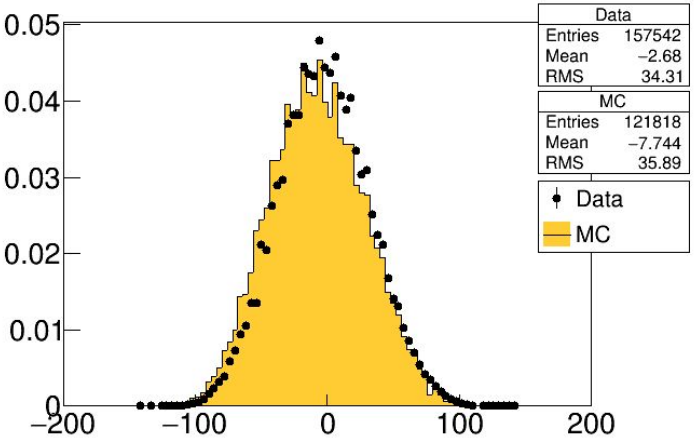

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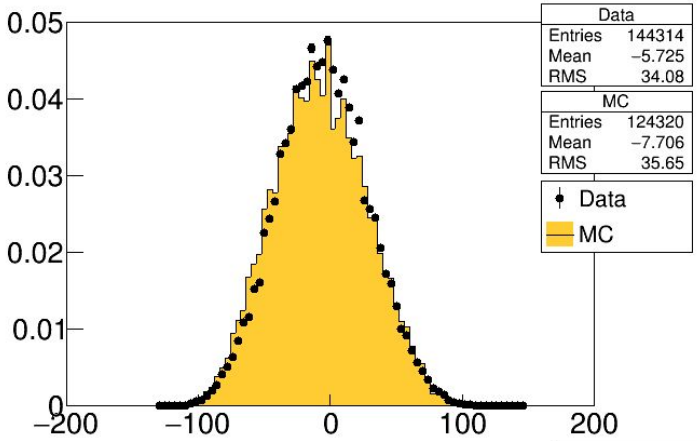

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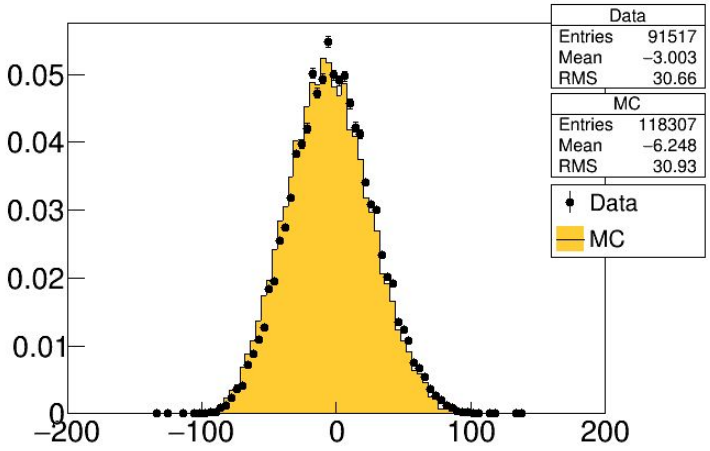

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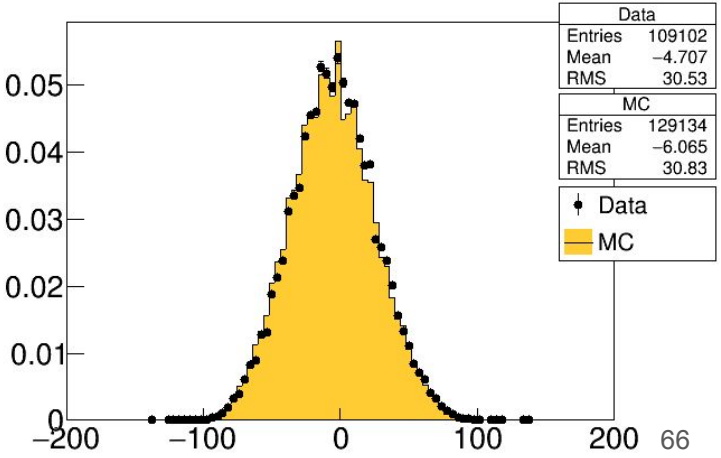

Y TKU

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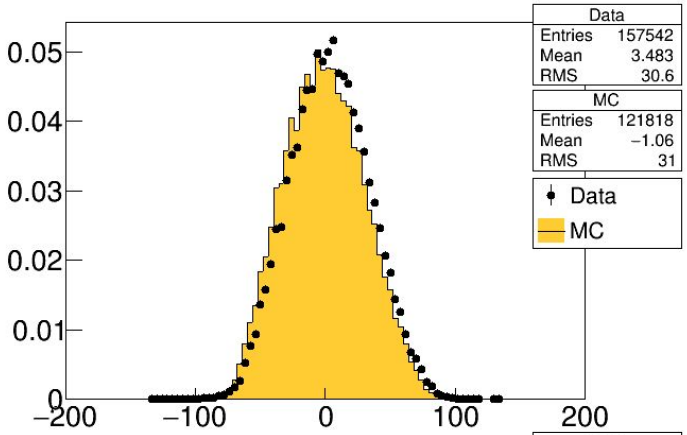
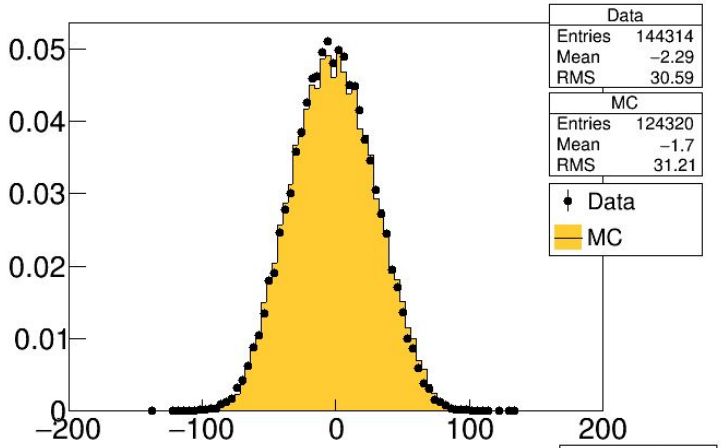


Empty LH2



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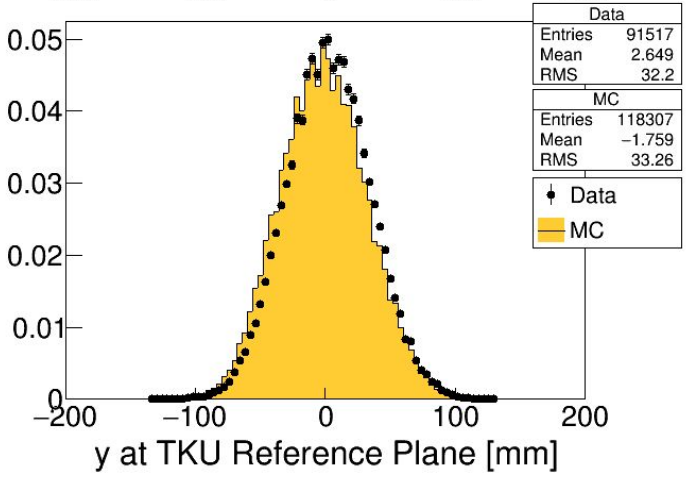

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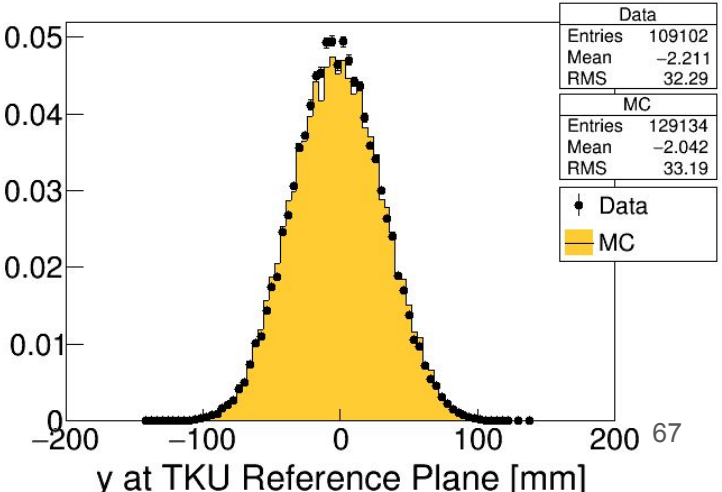

Y TKD

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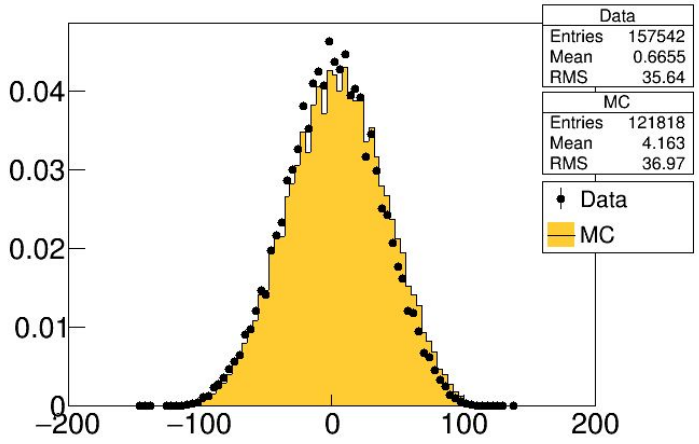
No abs



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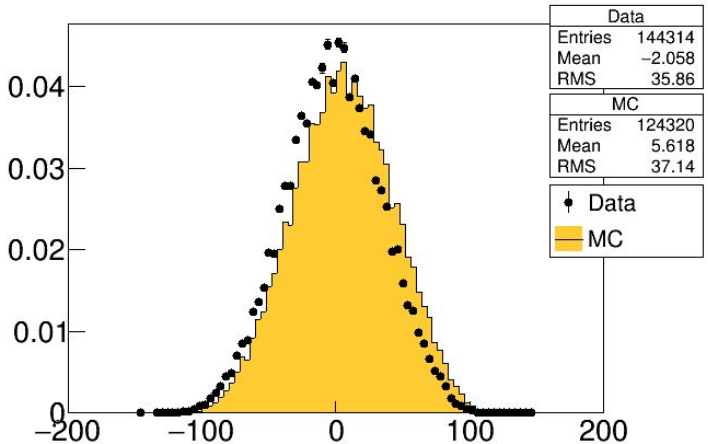
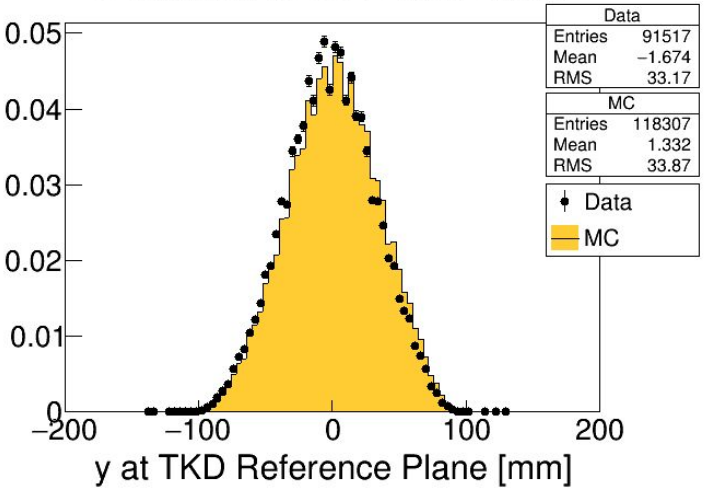
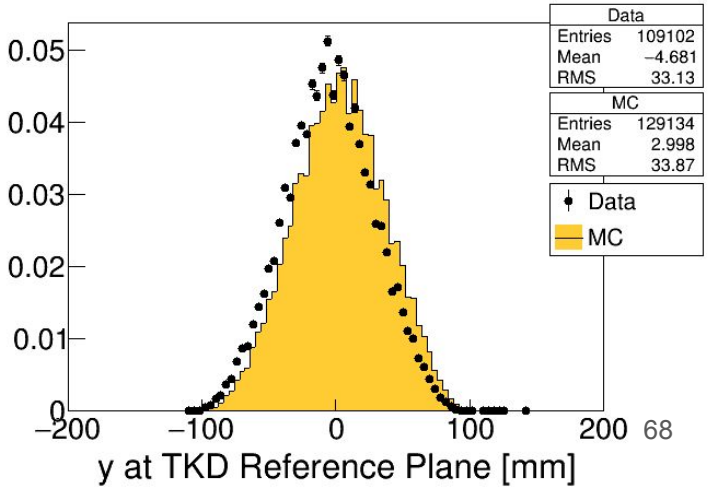


LiH



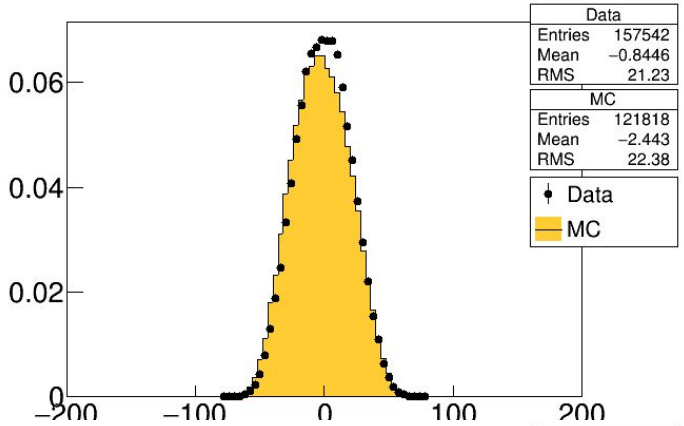
LH2



P_x TKU

Imperial College London

No abs



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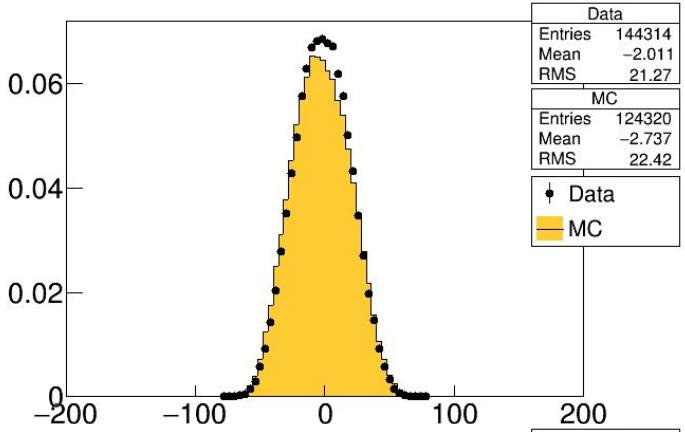
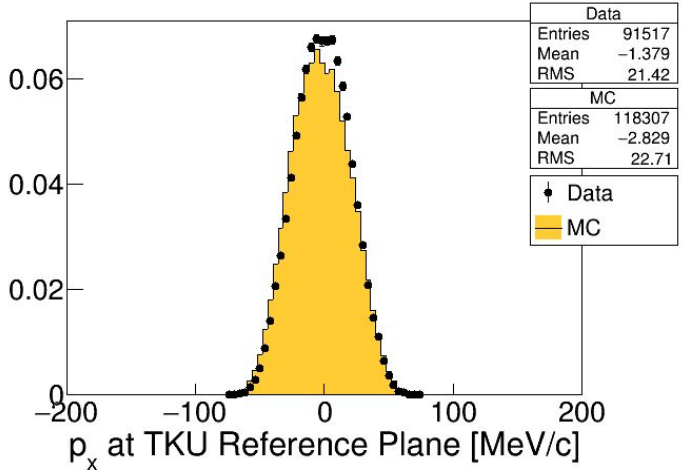


LiH



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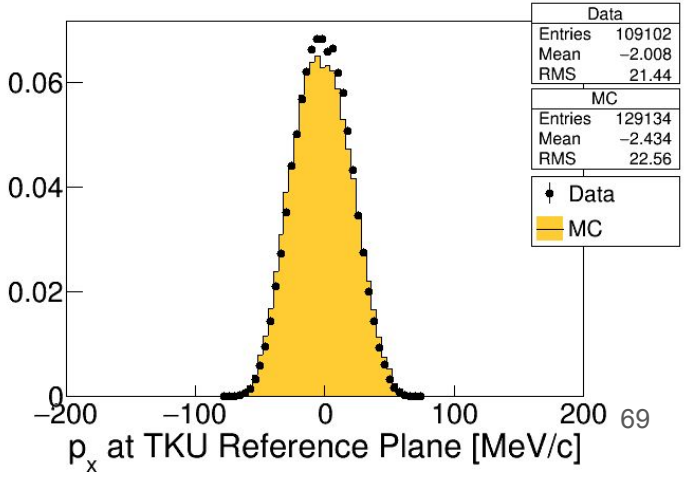

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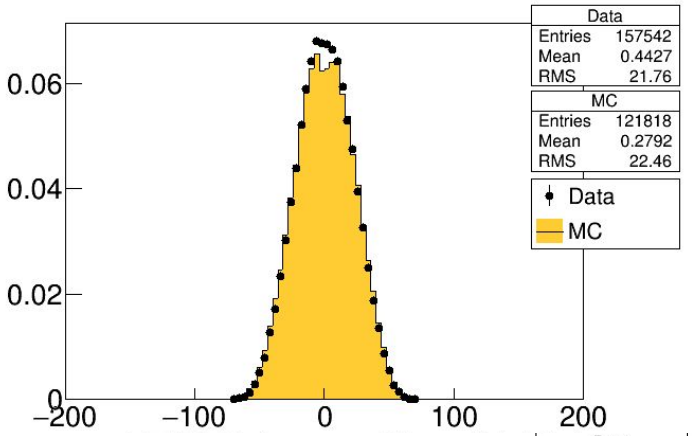

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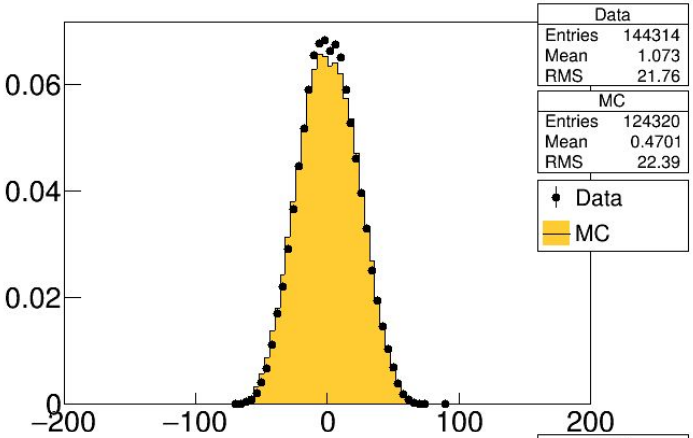

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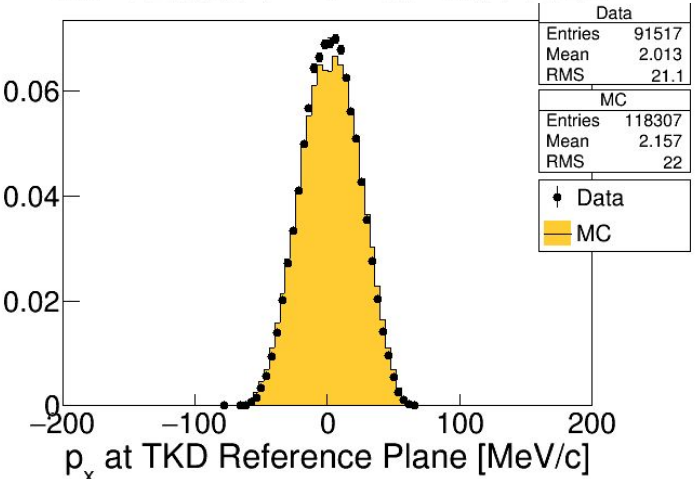

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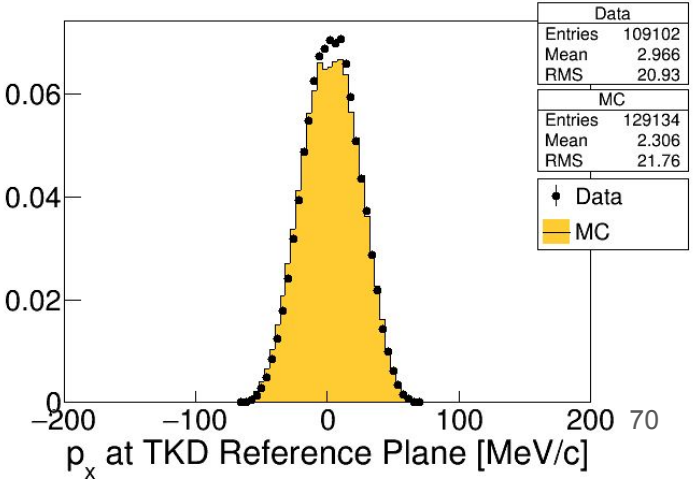

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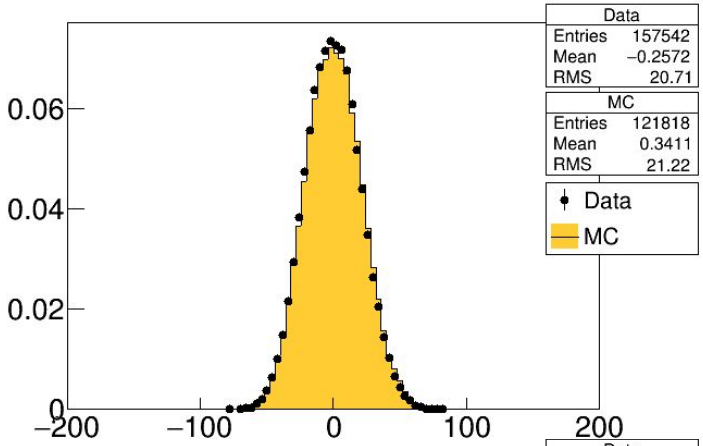

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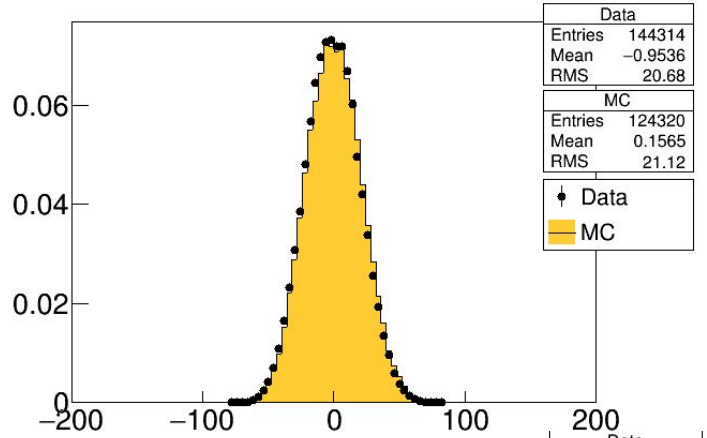

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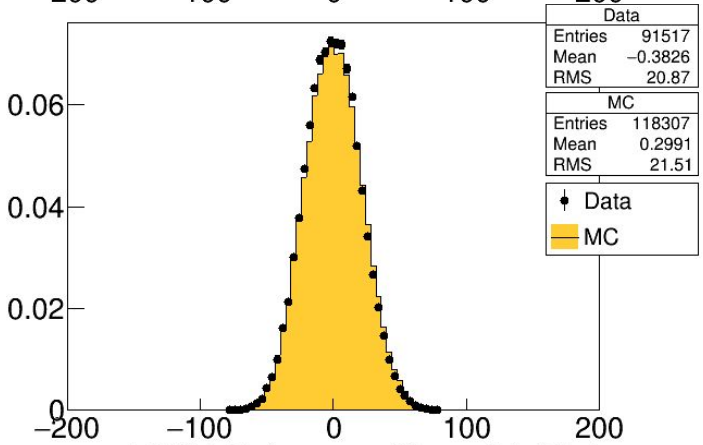

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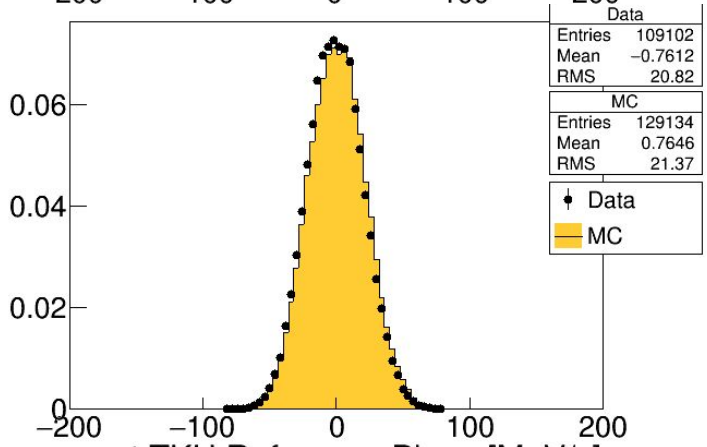

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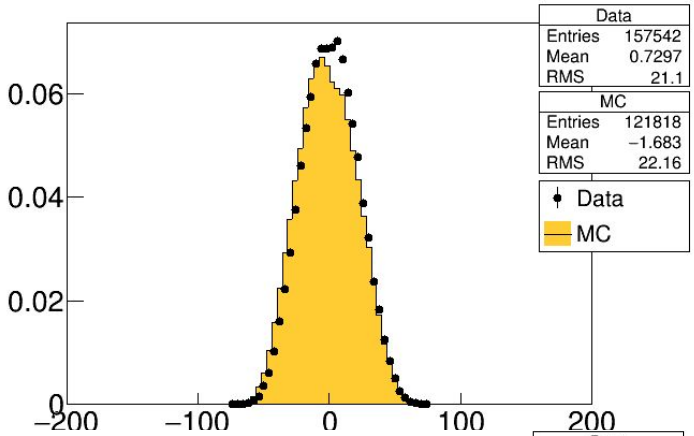

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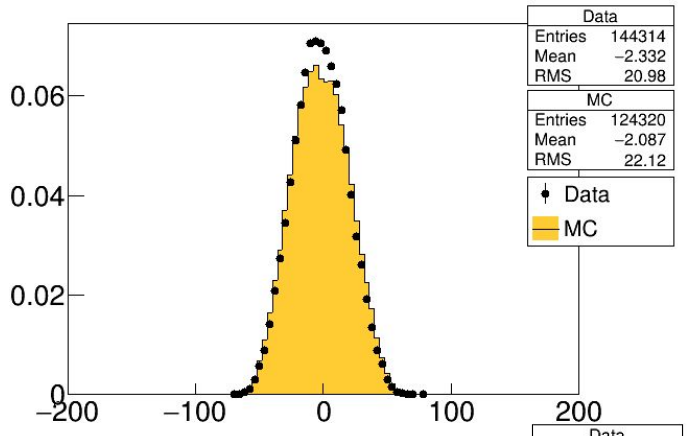

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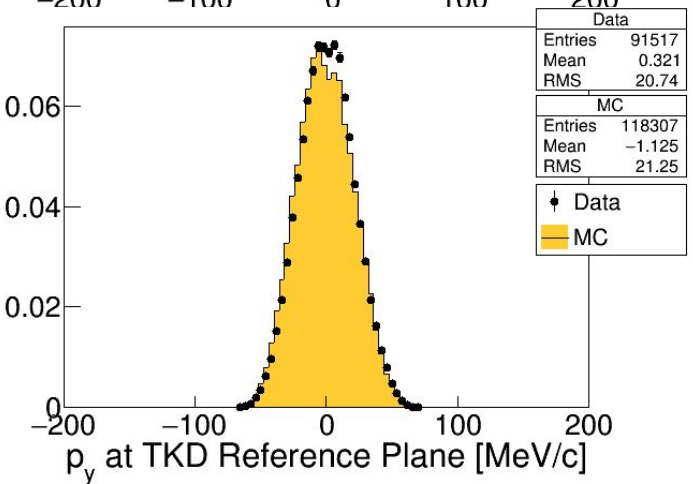

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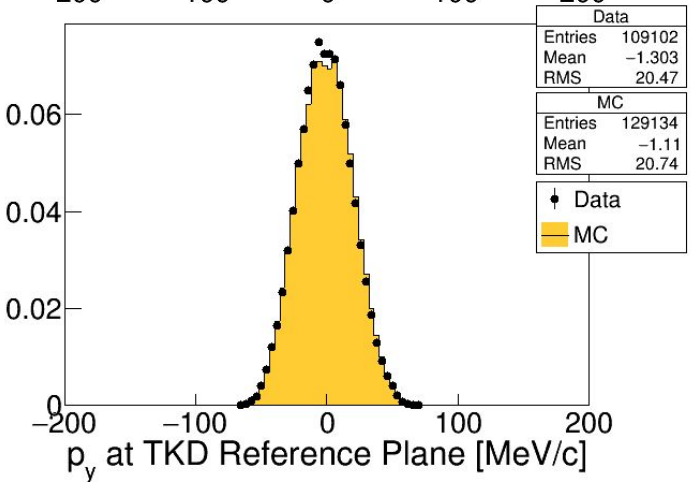

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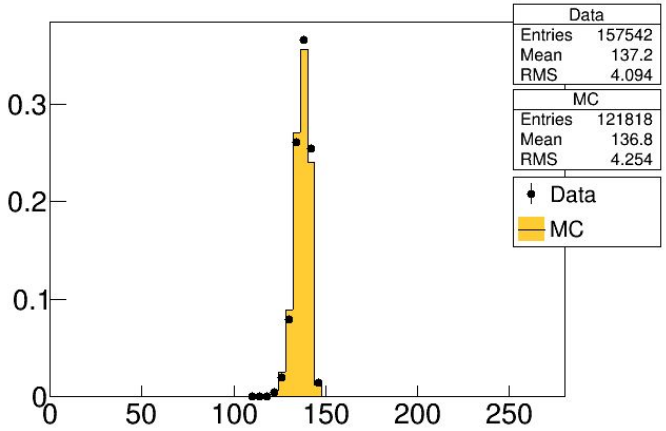

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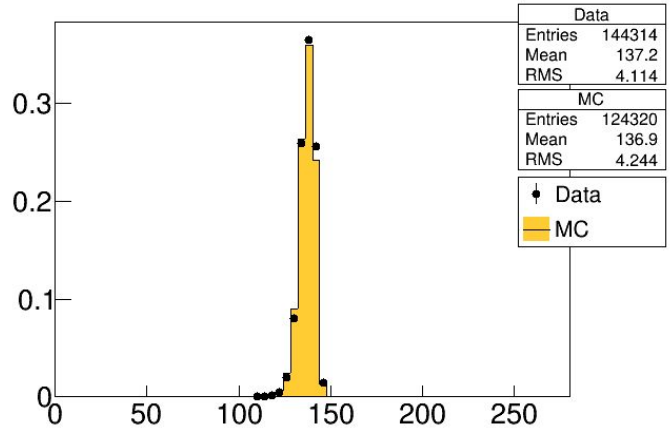

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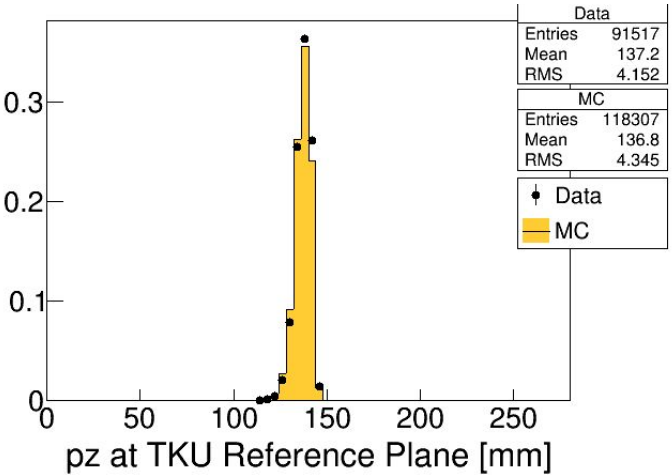

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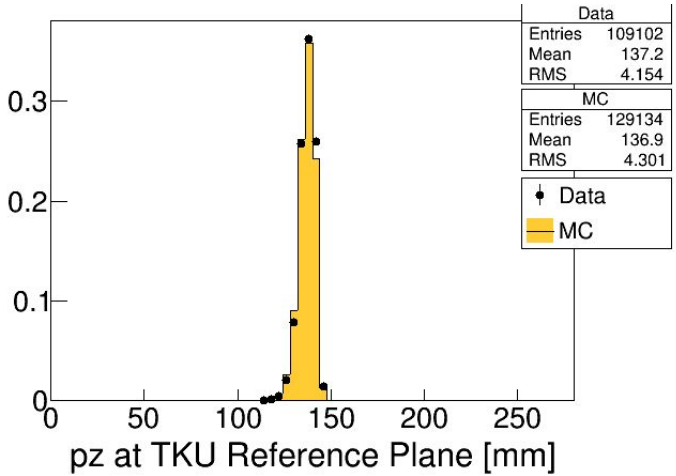

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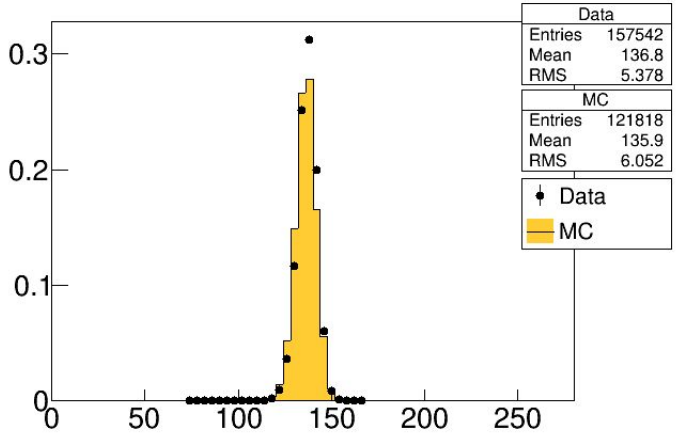

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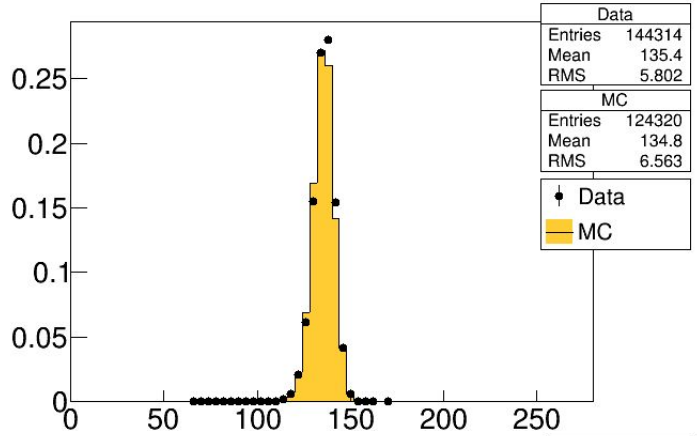

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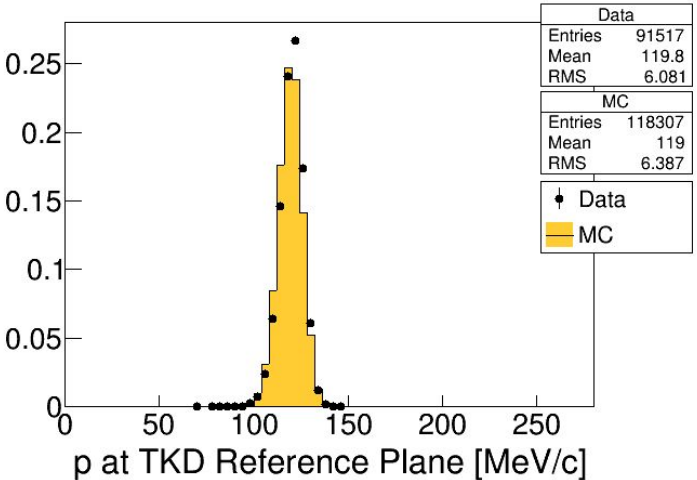

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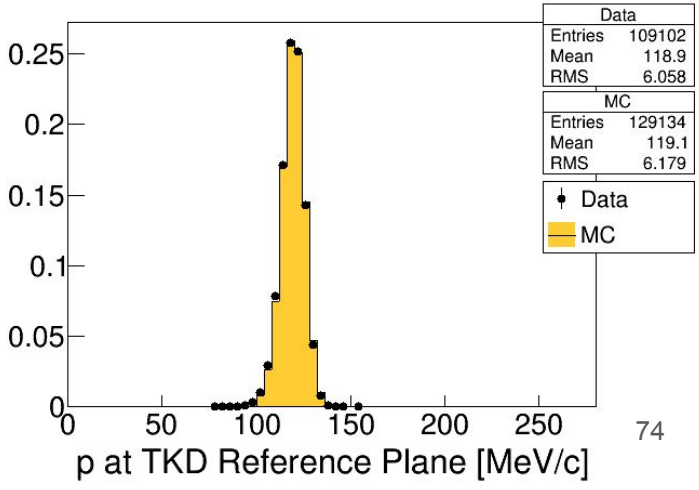

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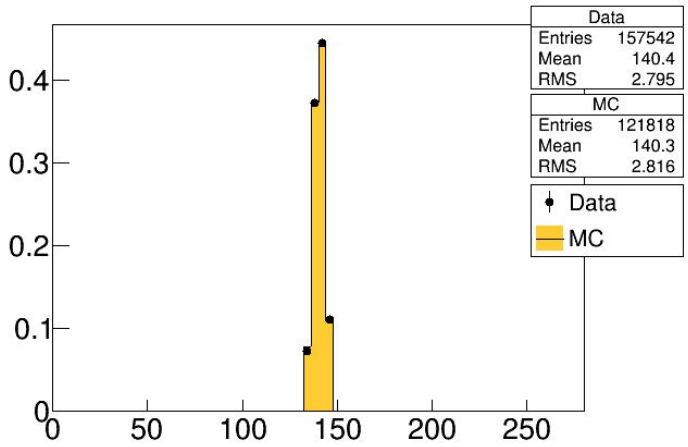

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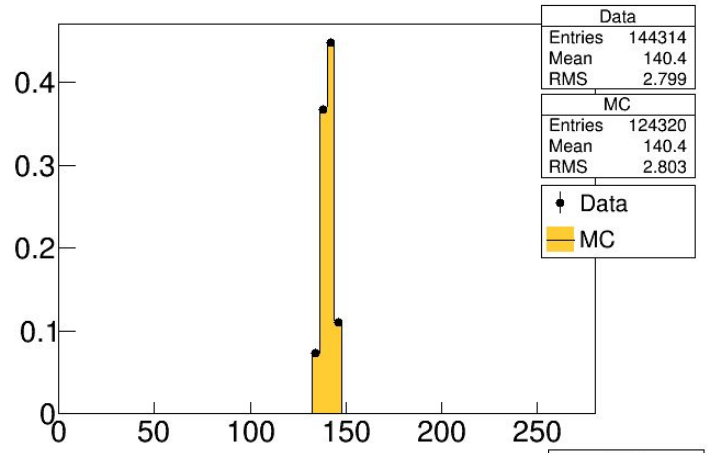

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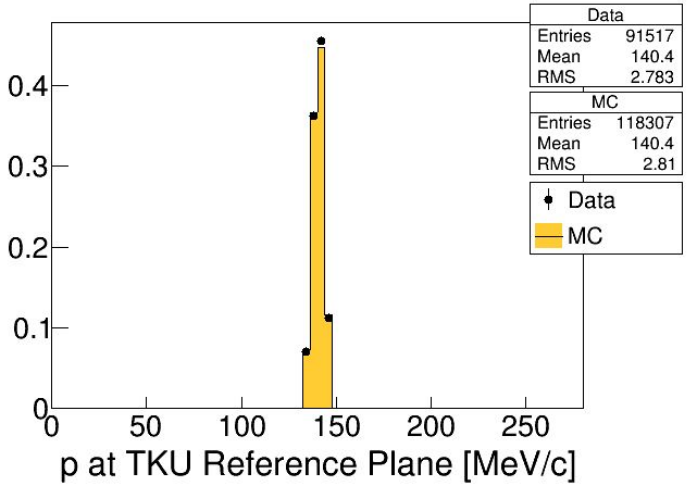

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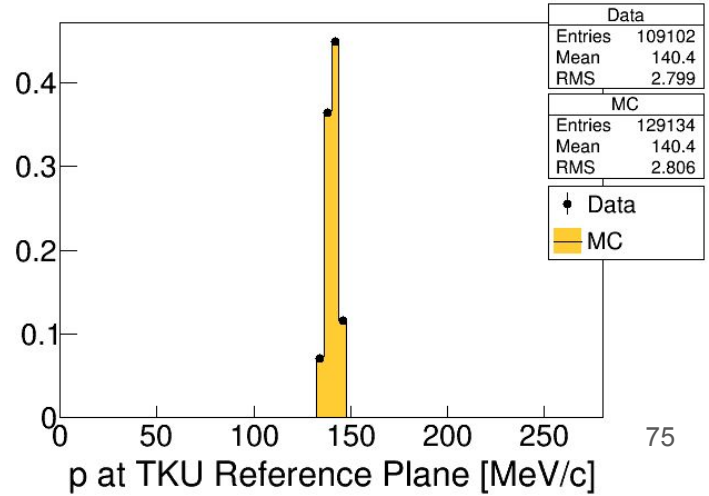

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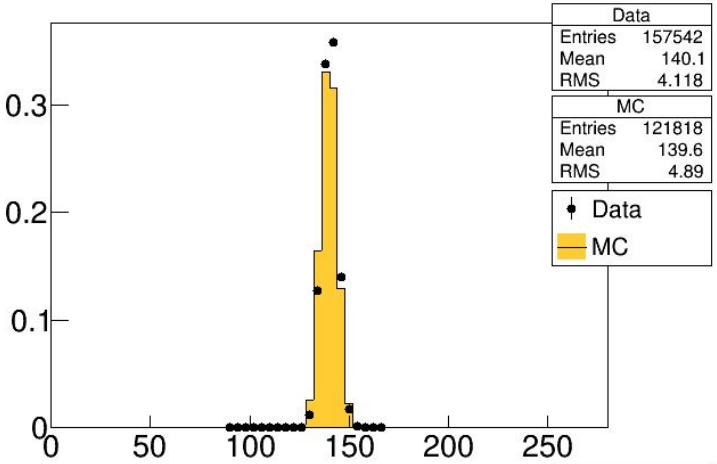

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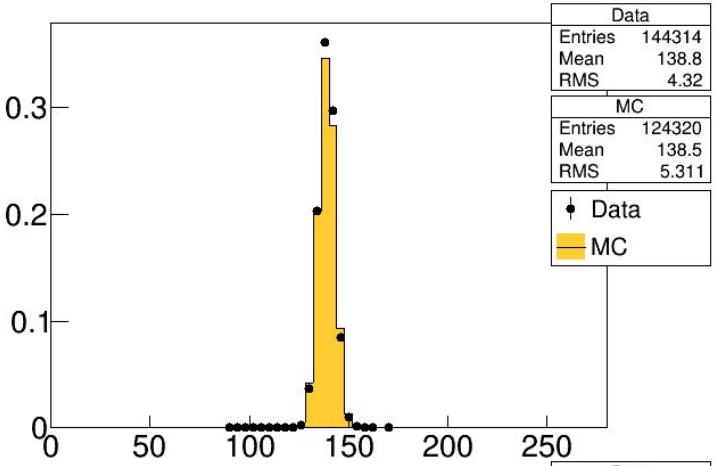

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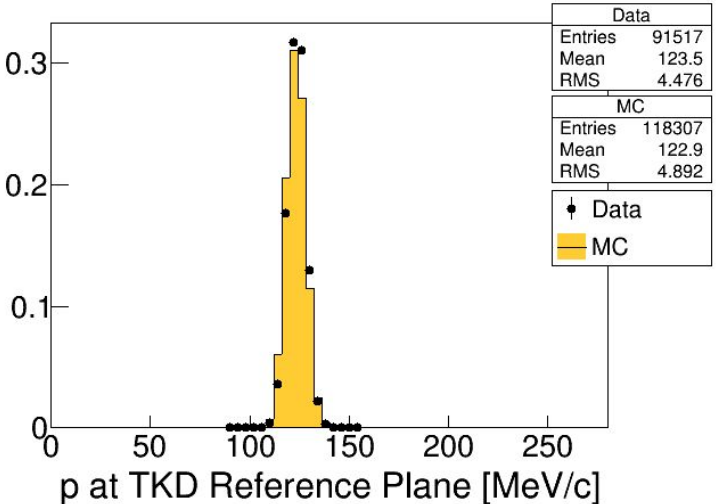

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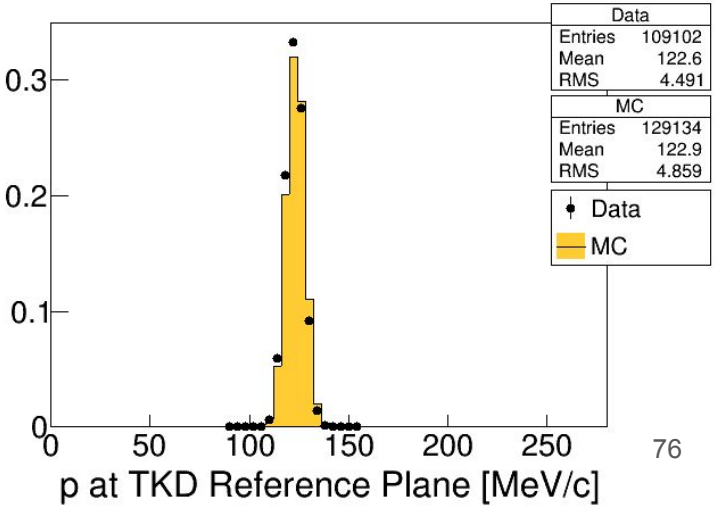

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Imperial College London

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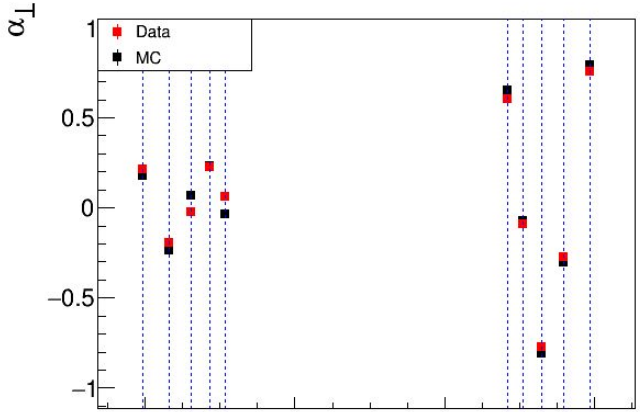

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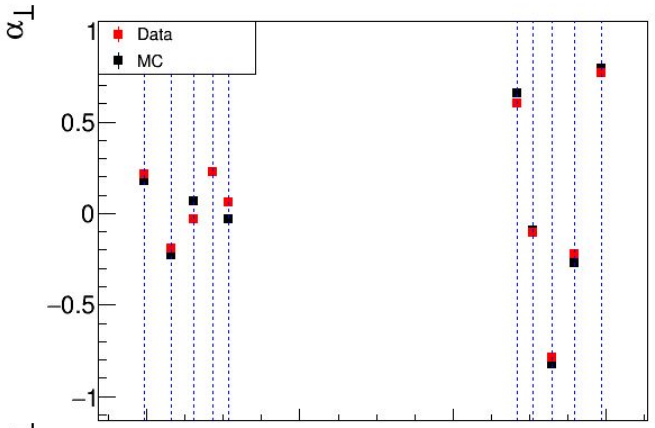

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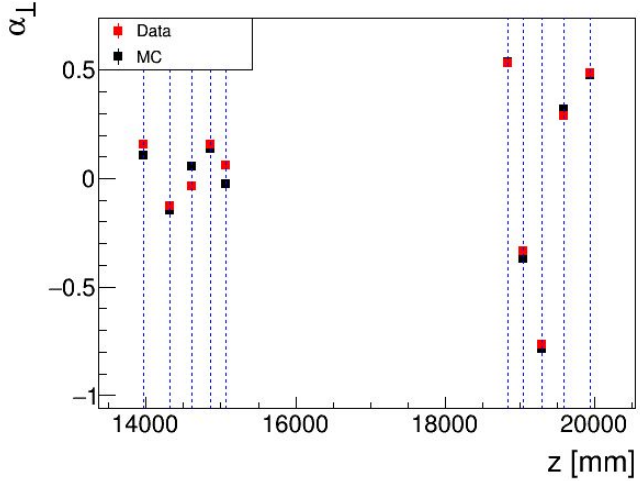

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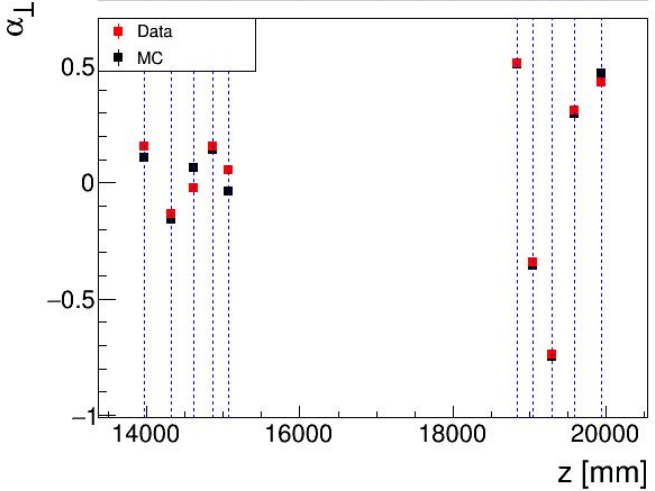

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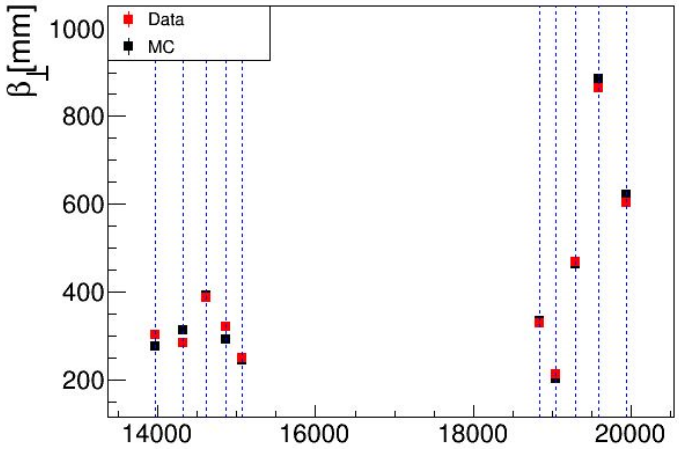

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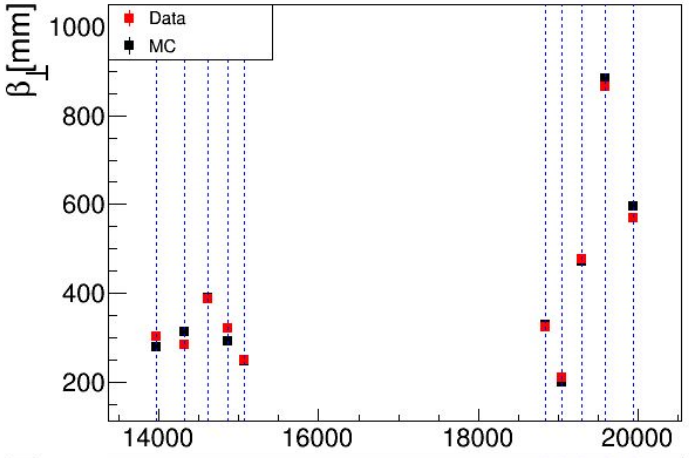

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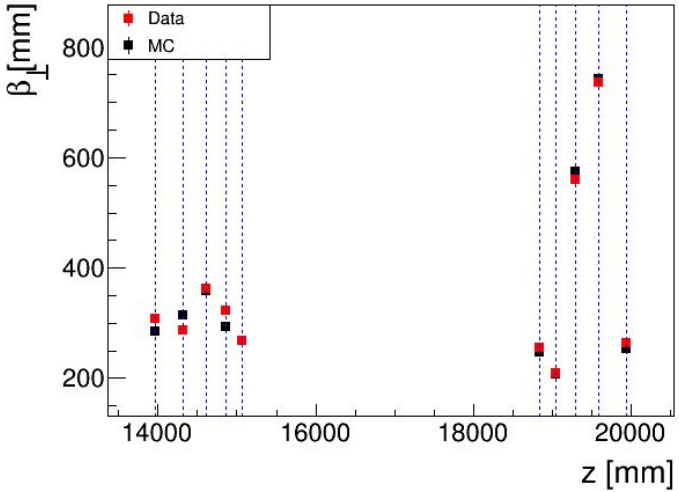

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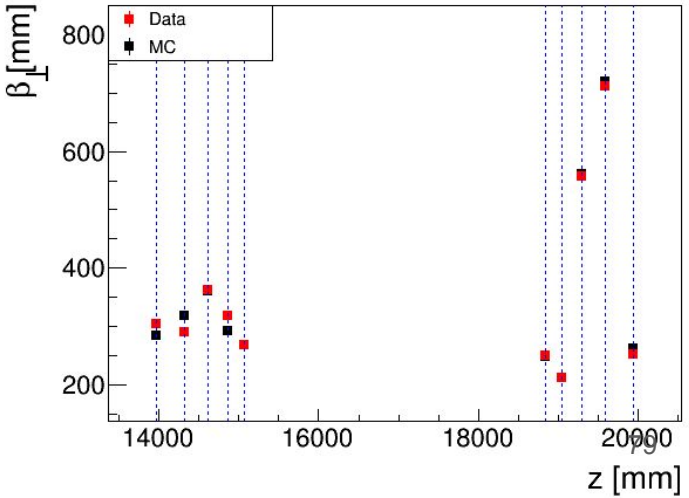

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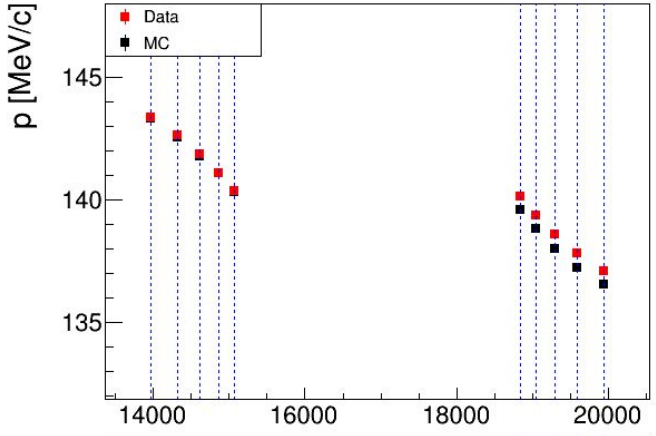

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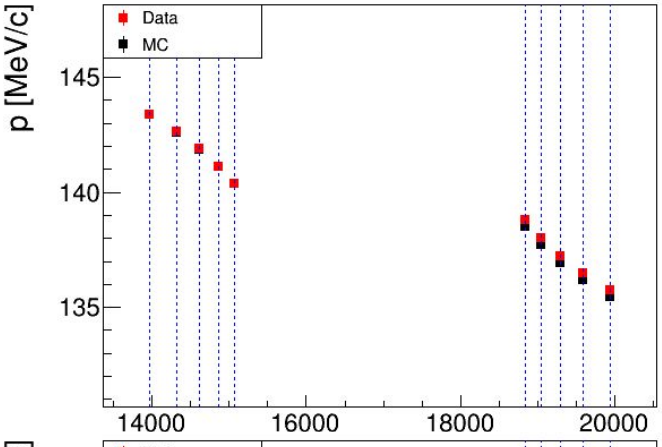

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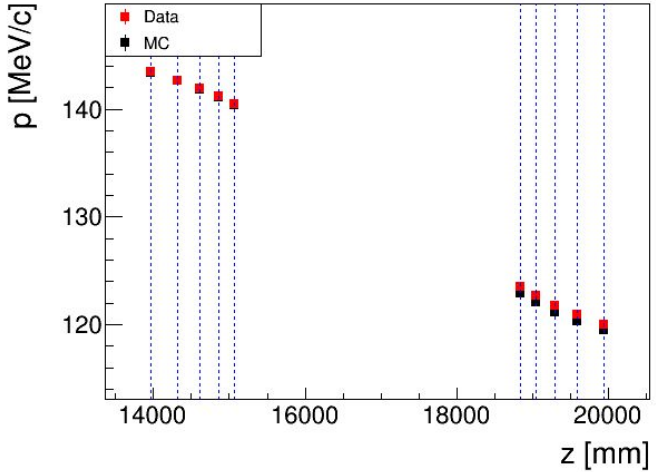

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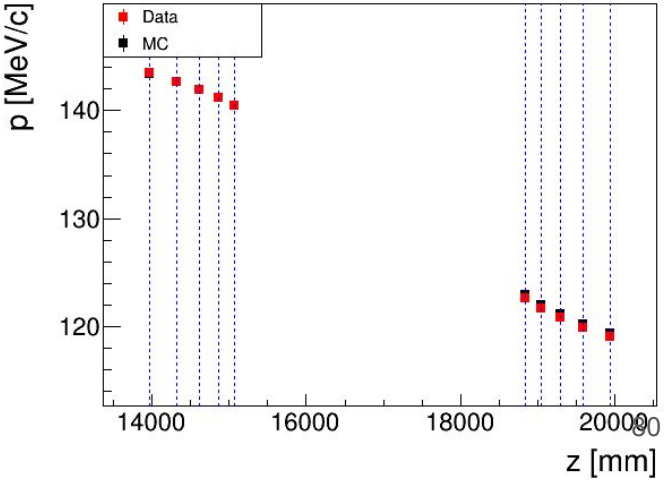

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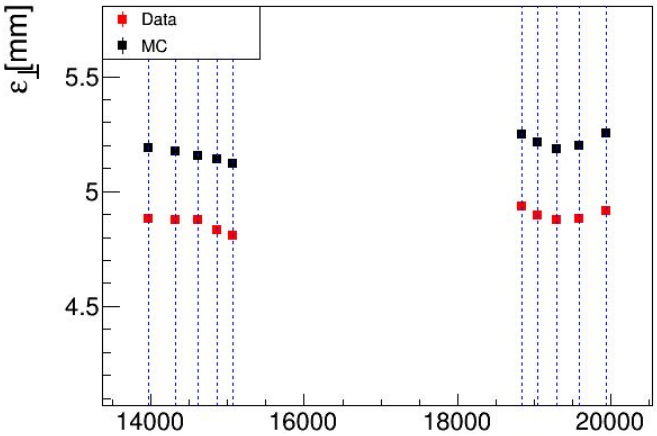

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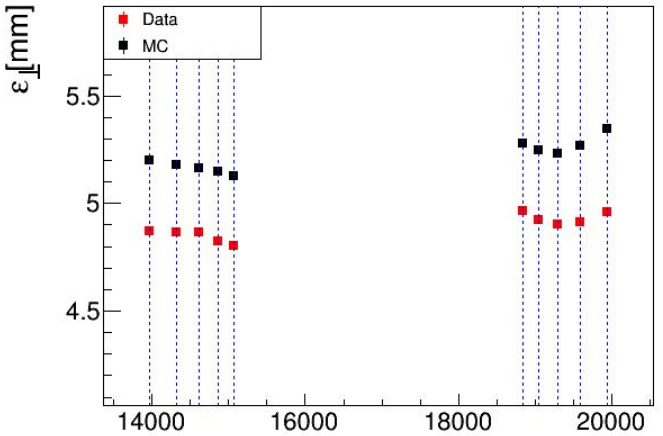

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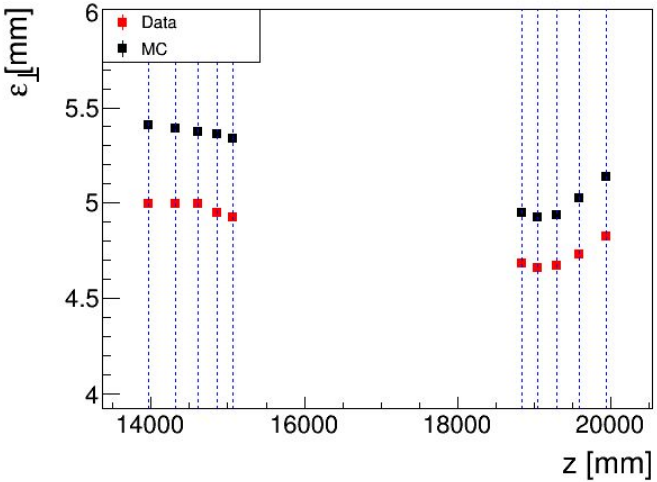

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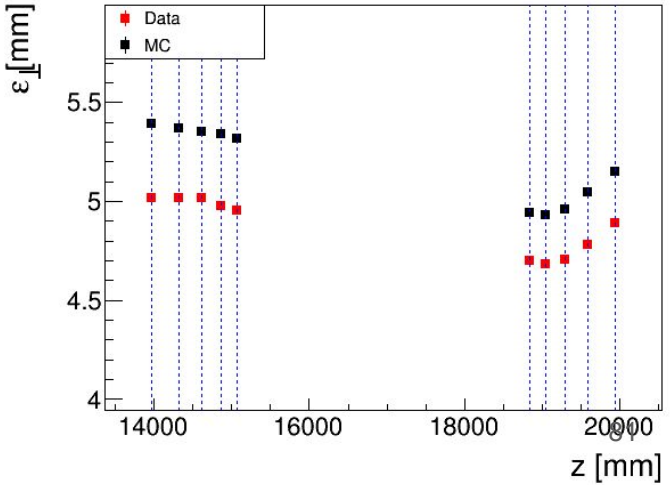

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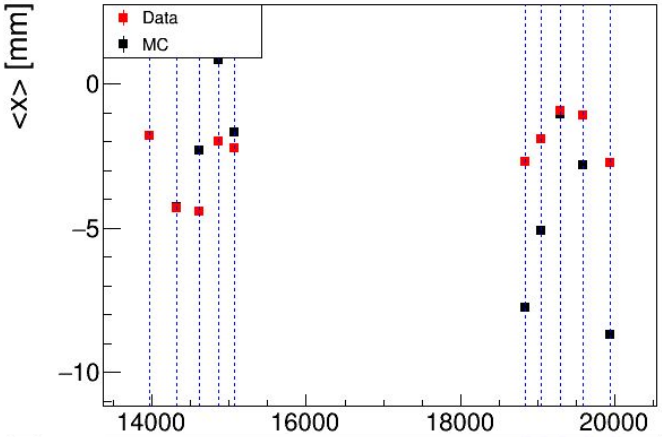

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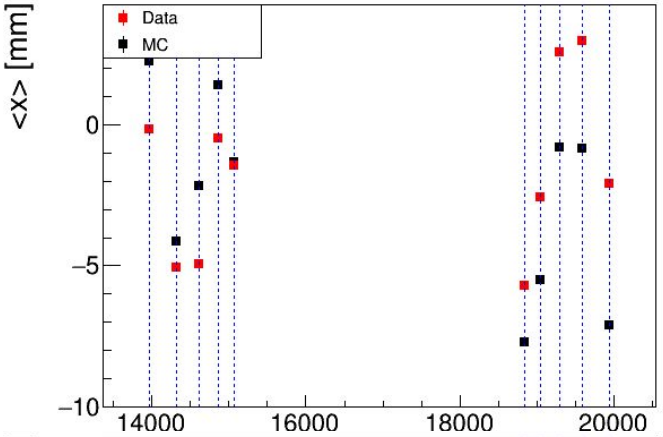

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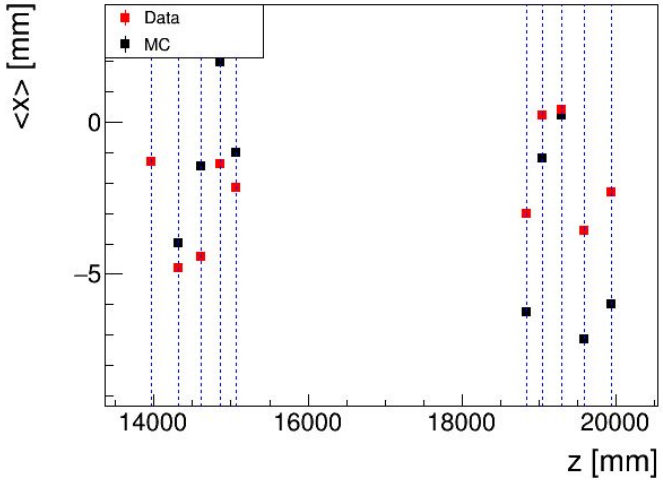

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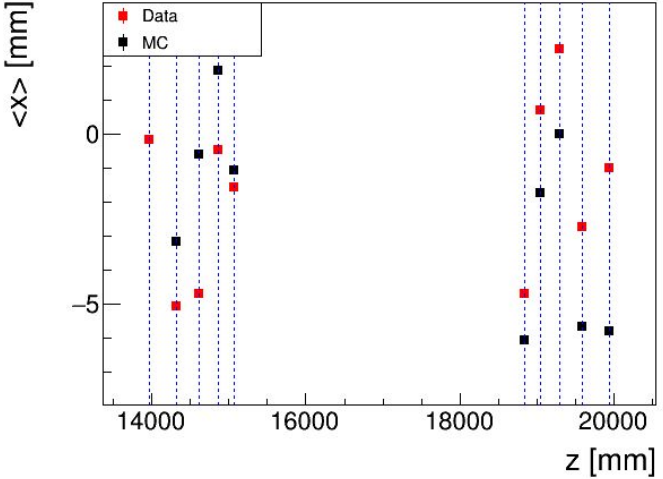

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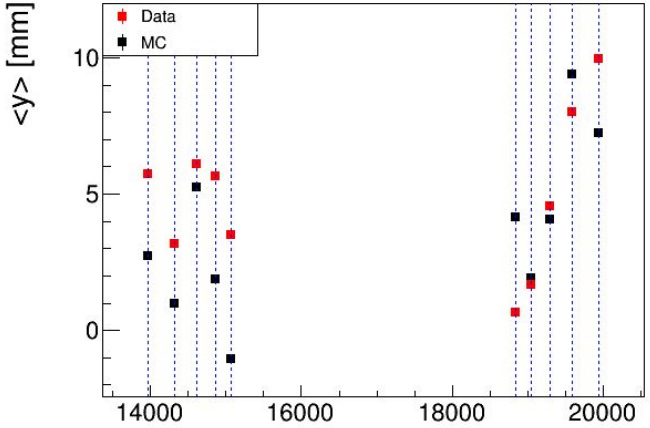

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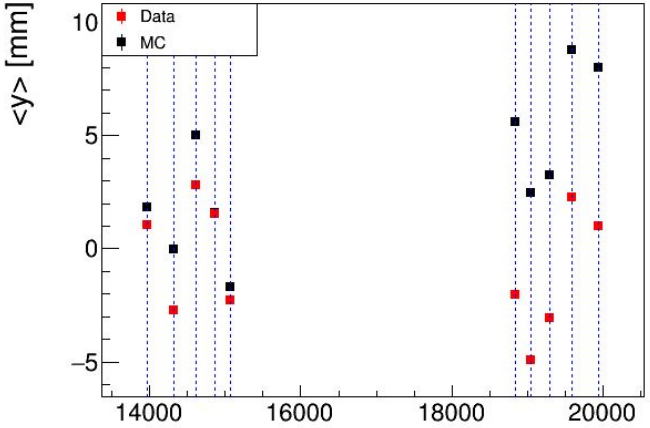

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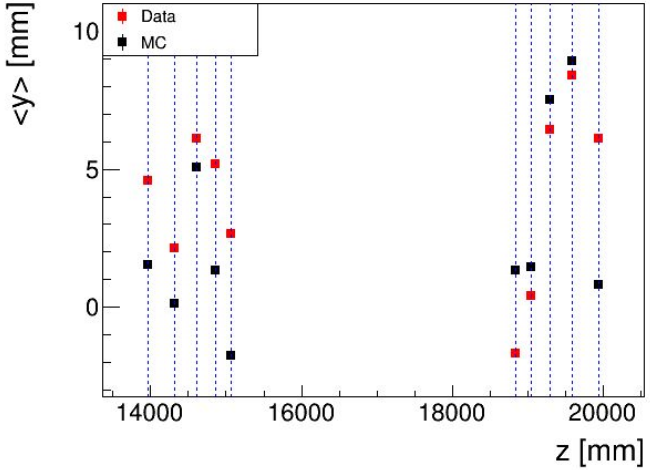

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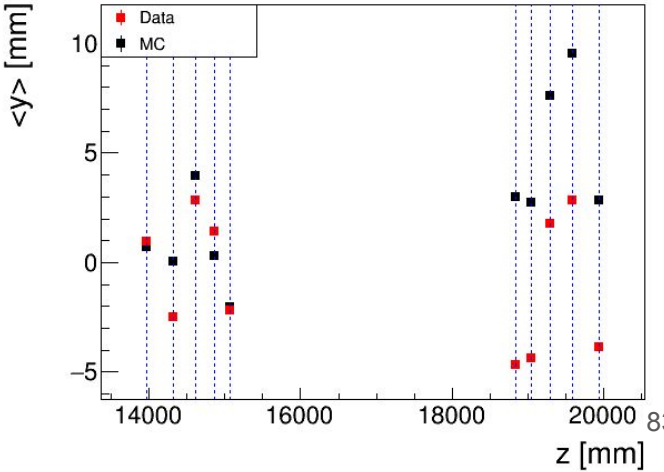

Mean P_x

Imperial College London

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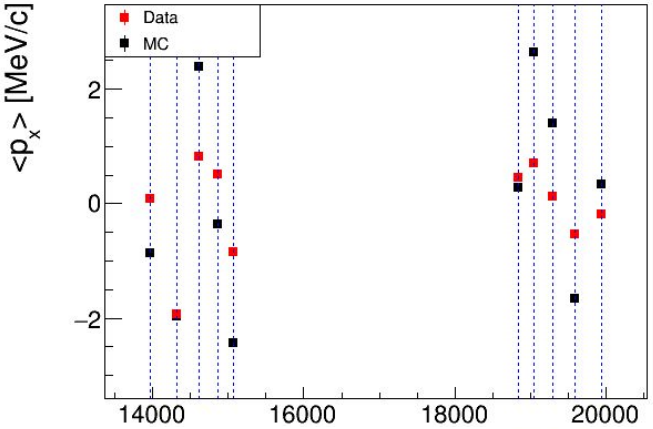

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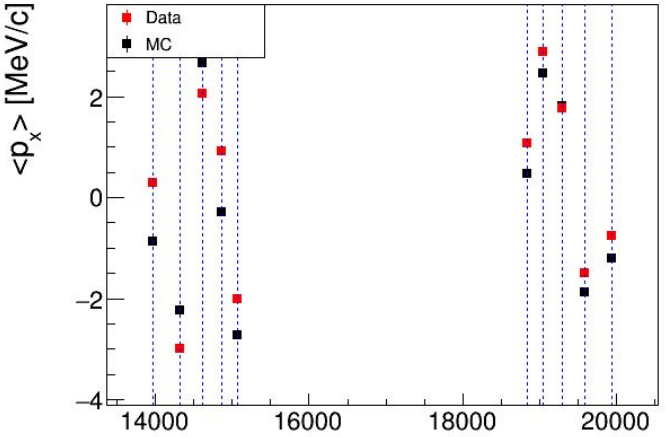

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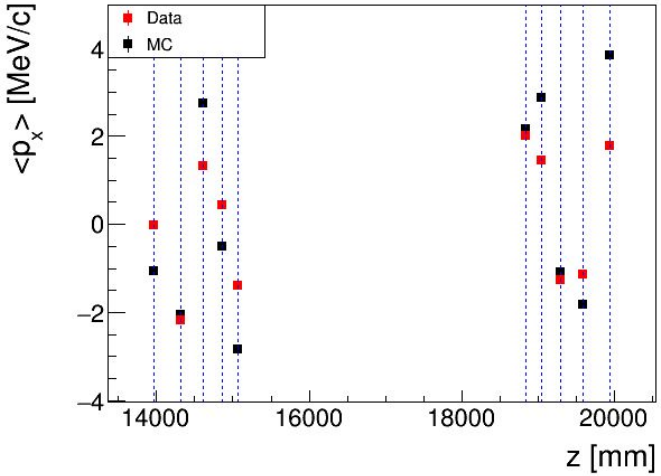

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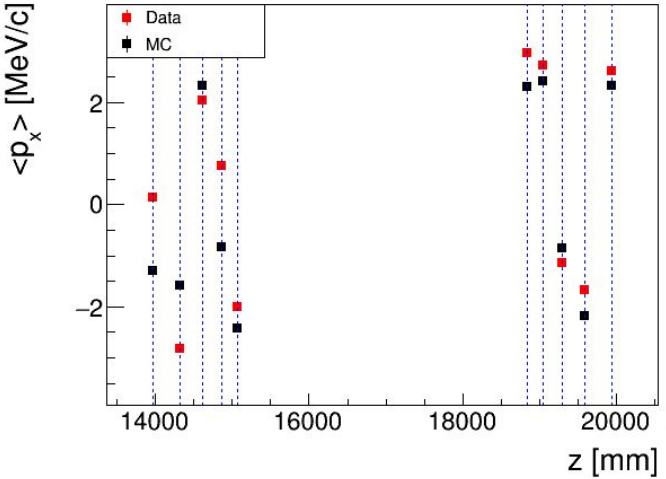

Mean P_y

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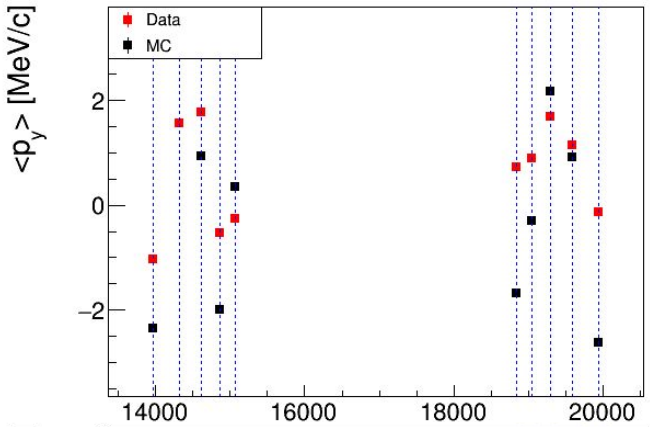

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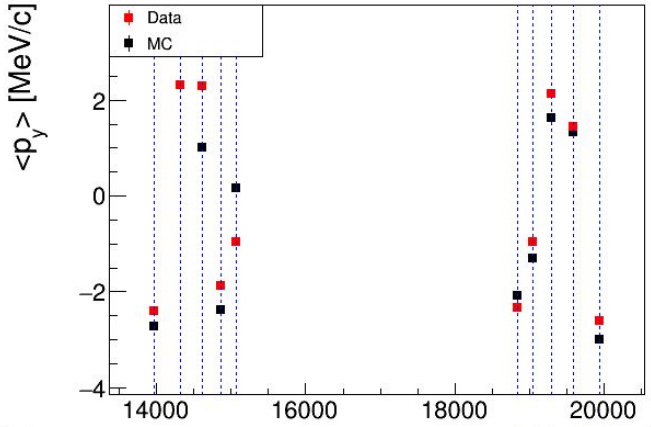
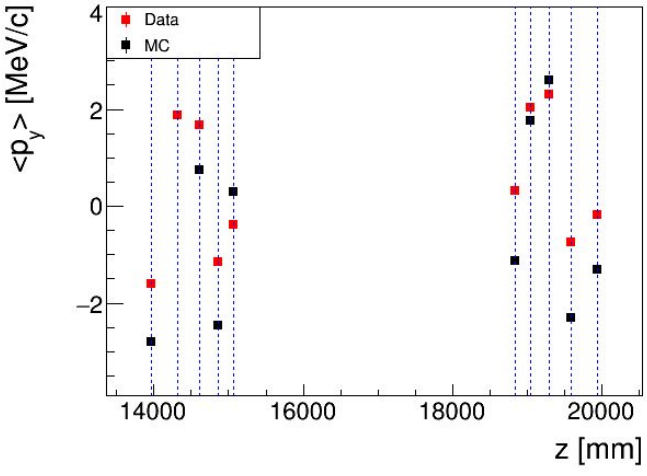
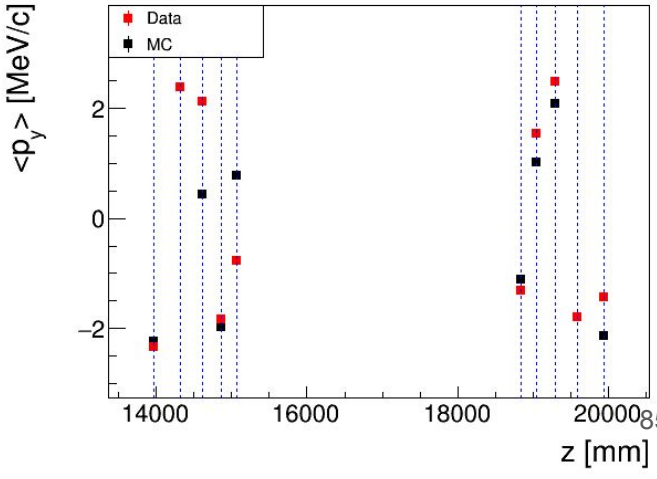


LiH



LH2



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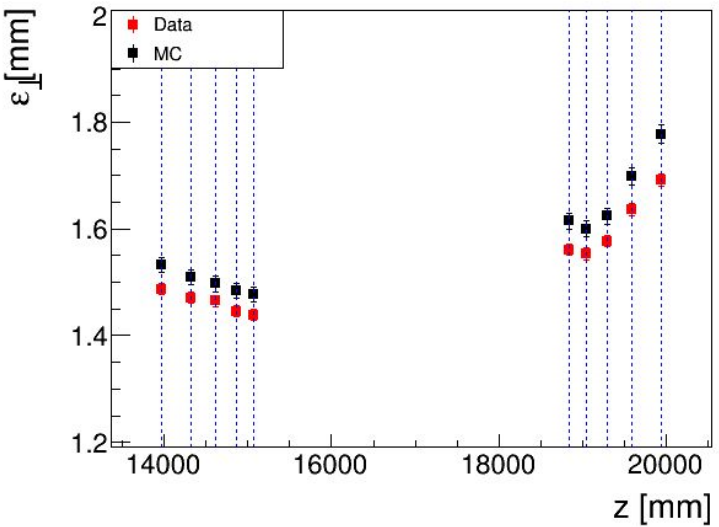
Sampled beams optics

Parent beams have optics discrepancies both in TKU and TKD

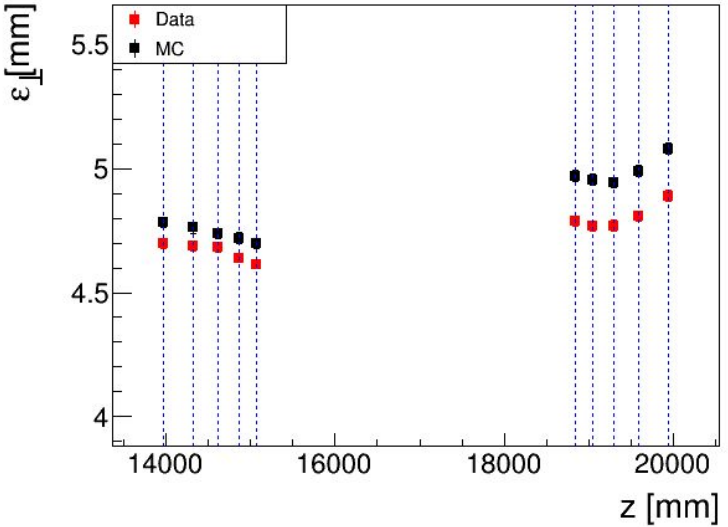
Beam sampling is supposed to largely iron out discrepancies in TKU

Next: optics of two sampled beams from 6-140 No absorber analysis

Emittance

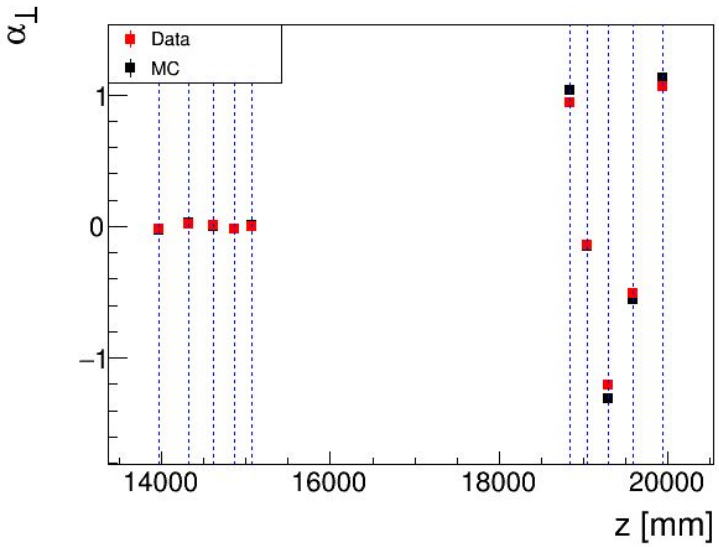


~ 1.5 mm beam

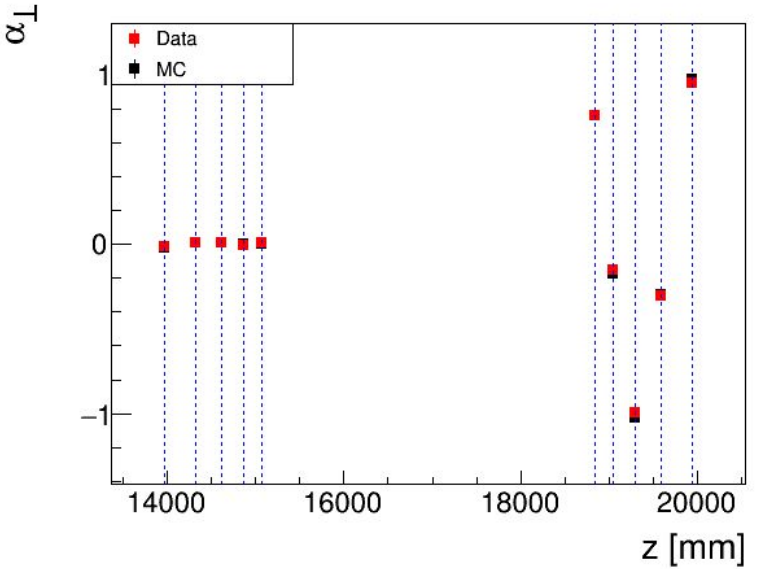


~ 4.7 mm beam

Alpha

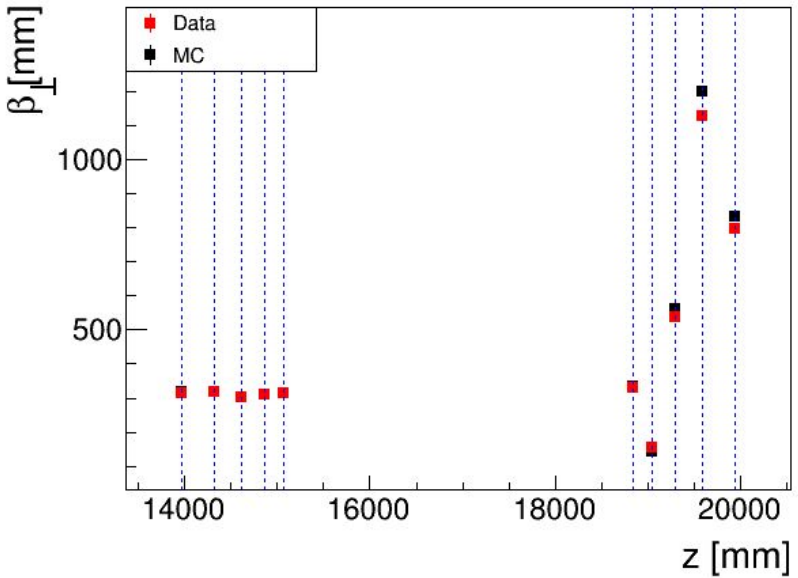


~ 1.5 mm beam

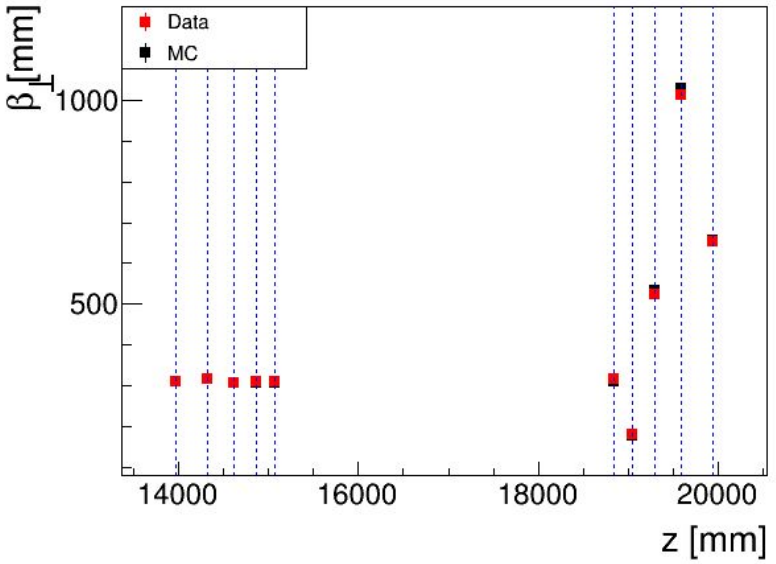


~ 4.7 mm beam

Beta

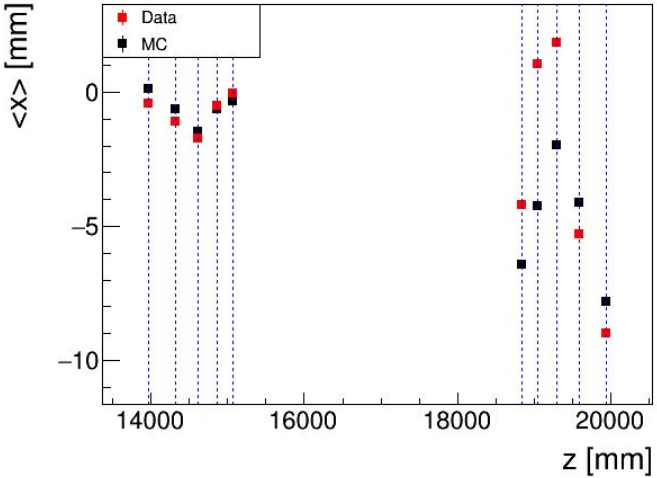


~ 1.5 mm beam

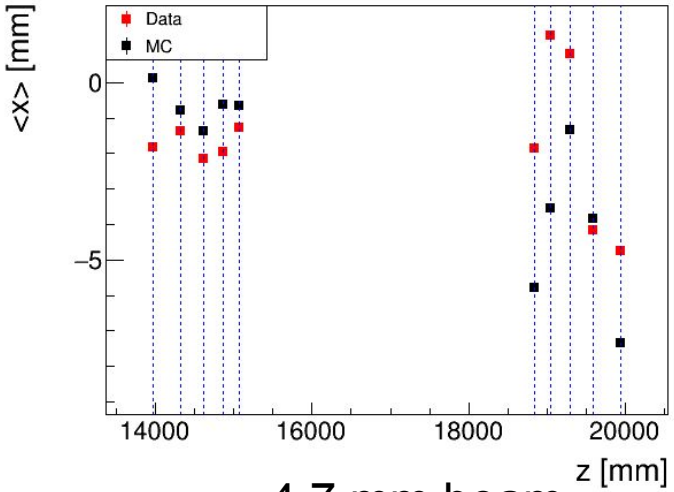


~ 4.7 mm beam

Mean X



~ 1.5 mm beam

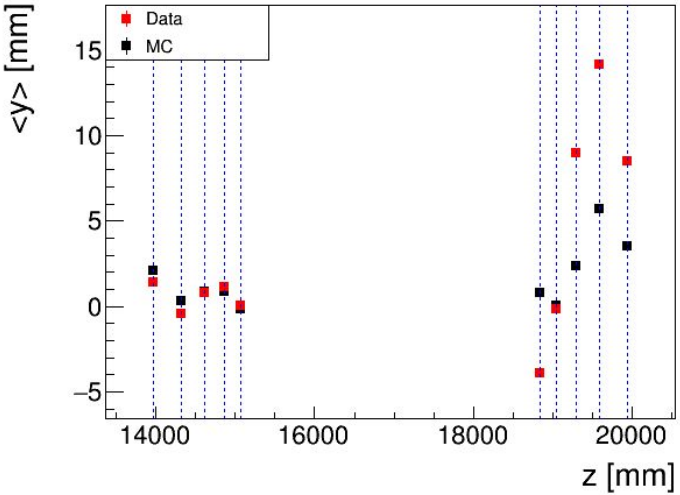


~ 4.7 mm beam

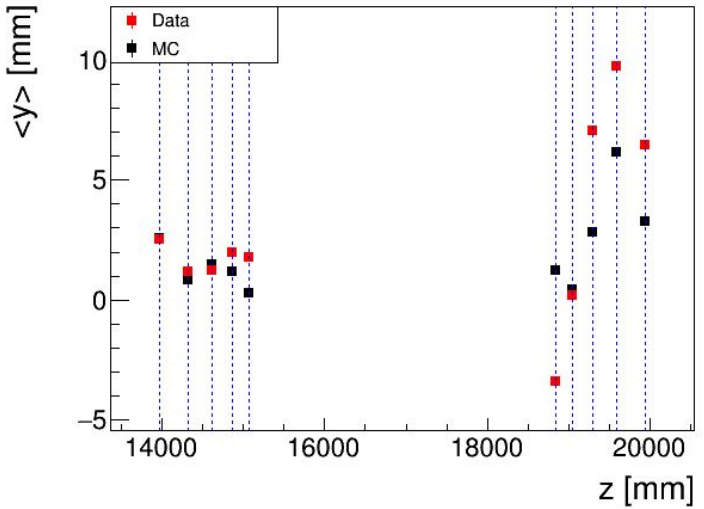
TKU agreement better for lower emittance beams

TKD discrepancies indicators of misalignment

Mean Y



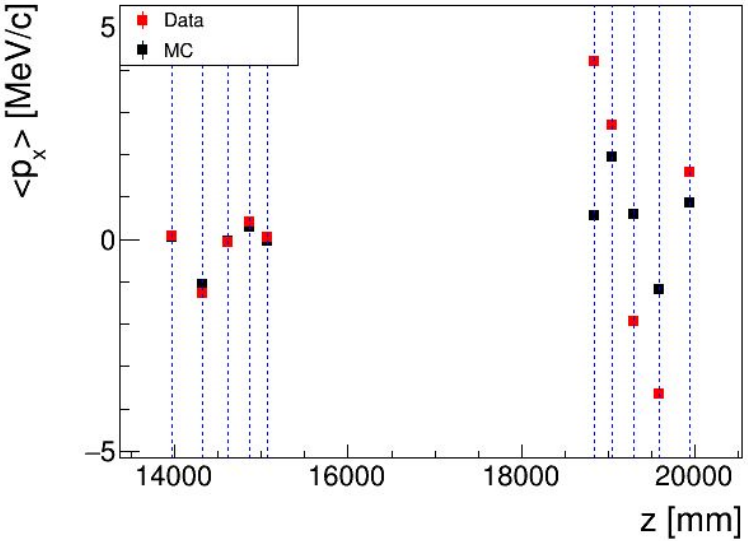
~ 1.5 mm beam



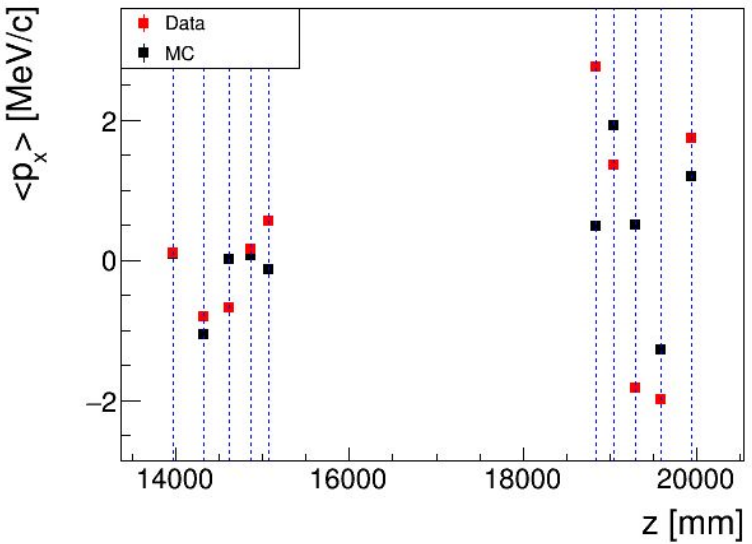
~ 4.7 mm beam

Misalignment generates differences in the amplitude and frequency of TKD oscillations

Mean P_x

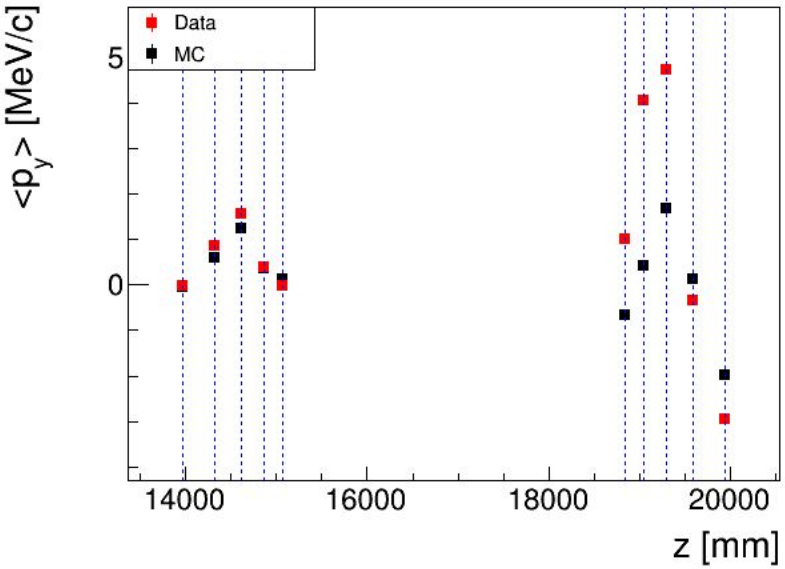


~ 1.5 mm beam

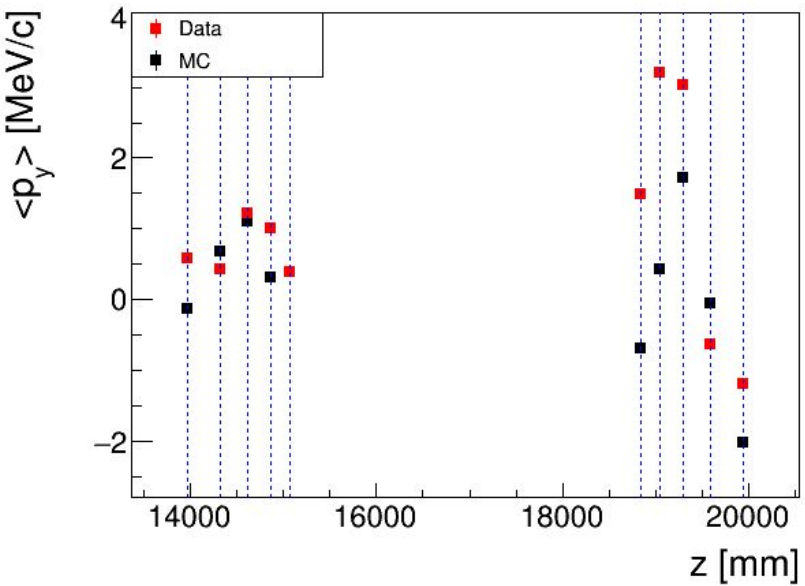


~ 4.7 mm beam

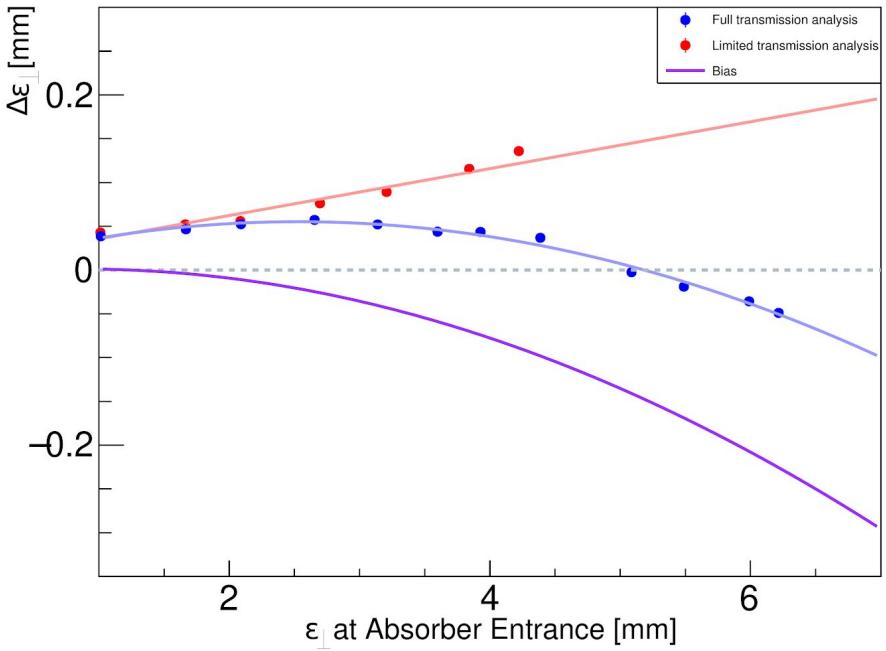
Mean P_y



~ 1.5 mm beam



~ 4.7 mm beam


Full transmission analysis
Limited transmission analysis
Bias
Δε⊥ [mm]
0.2
0
−0.2
2
4
6
ε⊥ at Absorber Entrance [mm]

Equilibrium emittance calculation

- used Bethe's mean stopping power formula to calculate dE/dz at 140 MeV/c
- parameters used for eqm. emittance:

LiH
$p = 140\,MeV/c$
$dE/dz = 1.925\,MeV/cm$
$X_0 = 102.04\,cm$
$\beta_\perp = 420\,mm$

LH_2
$p = 140\,MeV/c$
$dE/dz = 0.361\,MeV/cm$
$X_0 = 890.4\,cm$
$\beta_\perp = 420\,mm$

Statistical errors on absolute emittance change

- Starting from John Cobb's derivation of statistical errors on relative emittance change in Note 268
- John has also worked on this derivation and came up with a result
- Currently our results are not identical, will take some time to revise

$$\sigma^2_{\Delta\epsilon} = \frac{1}{2n}\left[(\epsilon_d - \epsilon_u)^2 + \epsilon_u\epsilon_d - \alpha^2\frac{\epsilon_u^3}{\epsilon_d}\right]$$